

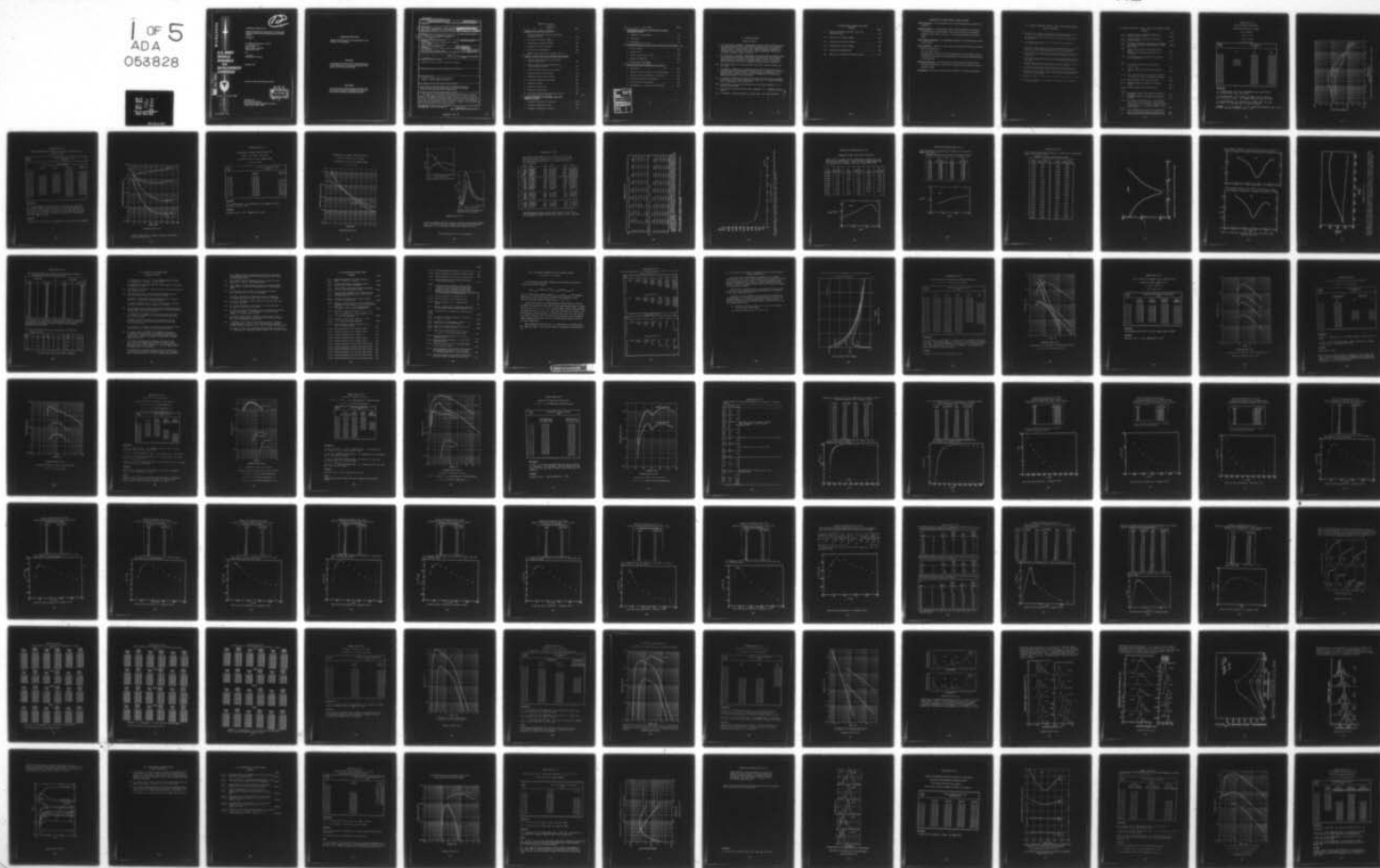
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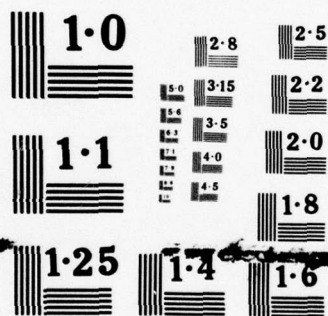
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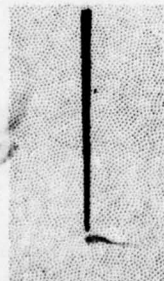


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TECHNICAL REPORT H-78-1

COMPILATION OF DATA RELEVANT TO RARE GAS-
RARE GAS AND RARE GAS-MONOHALIDE EXCIMER
LASERS

VOLUME II

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December 1977

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Lasers, Rare Gas-Rare Gas Excimers, Rare Gas-Monohalide Excimers, Cross Sections, Lifetimes, Reaction Rates, Transport Properties, Particle Collisions, and Potential Energy Curves		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report is a compilation of atomic data designed mainly to serve the needs of those engaged in research and development in the field of rare gas- halide and rare gas-rare gas excimer lasers. The bulk of the data relates to structural, radiative, and collisional properties of rare gas and halogen atoms and of the ions and molecules that can be formed from them. Two- and three- body collisions involving only heavy particles are covered, as are collisions of electrons and photons with the heavy particles.		

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(Volume II)

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C. ELECTRON COLLISIONS

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- R E.C. Beaty and J.W. Gallagher, "Bibliography of Low Energy Electron and Photon Cross Section Data-Supplement (1975) to NBS Special Publication 426," JILA Information Center Report No. 15, Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, Colorado (24 May, 1976). Complete listing of references on low-energy electron, positron, and photon two-body collisions for the year 1975, categorized according to type of collision.
- R E.C. Beaty and J.W. Gallagher, "Bibliography of Low Energy Electron and Photon Cross Section Data-Supplement (1976) to NBS Special Publication 426," JILA Information Center Report No. 17, University of Colorado, Boulder, Colorado (10 May, 1977). Complete listing of references on low-energy electron, positron, and photon two-body collisions for the year 1976, categorized according to type of collision.
- D,R J.B. Hasted, "Physics of Atomic Collisions" (Second Ed.), American Elsevier, New York (1972).
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- D,R H.S.W. Massey and E.H.S. Burhop, "Electronic and Ionic Impact Phenomena," Vol. 1, Clarendon, Oxford (1969).
- D,R H.S.W. Massey, "Electronic and Ionic Impact Phenomena," Vol. 2, Clarendon, Oxford (1969).
- D,R E.W. McDaniel, "Collision Phenomena in Ionized Gases," Wiley, New York (1964).

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DEFINITIONS OF VARIOUS KINDS OF CROSS SECTIONS

Total Scattering - the cross section for all scattering events, elastic and inelastic.

Momentum Transfer - a total elastic cross section obtained by integrating the differential center-of-mass elastic cross section over all angles weighted by the factor $(1 - \cos \theta)$. θ is the center-of-mass scattering angle.

Total Elastic Scattering - the unweighted integral of the differential elastic cross section.

Total Ionization - this is, in fact, the cross section for electron production and is also defined as

$$\sigma_T = \sigma_1 + 2\sigma_2 + 3\sigma_3 + \dots$$

The subscripts on the σ 's on the right hand side of the equation are the individual cross sections for producing ions of positive charge indicated by the subscript.

Electronic Excitation - as used here this term is the total cross section for direct excitation of the atomic or molecular level indicated, unless otherwise noted.

Fluorescence - the total cross section for emission of radiation indicated.

C-1. ELECTRON SCATTERING: ELASTIC, TOTAL, AND MOMENTUM TRANSFER

General References

- D,R B. Bederson and L.J. Kieffer, "Total Electron-Atom Collision Cross Sections at Low Energies - A Critical Review," *Rev. Mod. Phys.*, Vol. 43, pg. 601 (1971).
- R.A. Bonham and M. Fink, "High Energy Electron Scattering," Van Nostrand Reinhold, New York (1974).
- D,R P. G. Burke and J. F. Williams, "Electron Scattering by Atoms and Molecules," *Physics Reports* (1978).
- D M. Fink and J. Ingram, "Theoretical Electron Scattering Amplitudes and Spin Polarizations," *Electron Energies 100 to 1500 eV, Part II. Be, N, O, Al, Cl, V, Co, Cu, As, Nb, Ag, Sn, Sb, I, and Ta Targets*, *Atomic Data*, Vol. 4, pg. 129 (1972).
- D M. Fink and A.C. Yates, "Theoretical Electron Scattering Amplitudes and Spin Polarizations," *Selected Targets, Electron Energies 100 to 1500 eV*, *Atomic Data*, Vol. 1, pg. 385 (1970).
- D D. Gregory and M. Fink, "Theoretical Electron Scattering Amplitudes and Spin Polarizations," *Electron Energies 100 to 1500 eV*, *Atomic Data and Nuclear Data Tables*, Vol. 14, 39 (1974).
- D Y. Itikawa, "Momentum-Transfer Cross Sections for Electron Collisions with Atoms and Molecules," *Atomic Data and Nuclear Data Tables*, Vol. 14, pg. 1 (1974).
- D,R L.J. Kieffer, "Low-Energy Electron-Collision Cross-Section Data," Part III: Total Scattering: Differential Elastic Scattering, *Atomic Data*, Vol. 2 p. 293 (1971).
- D,R M.E. Riley, C.J. MacCallum, and F. Biggs, "Theoretical Electron-Atom Elastic Scattering Cross Sections," *Selected Elements, 1 keV to 256 keV*, *Atomic Data and Nuclear Data Tables*, Vol. 15, pg. 443 (1975).
- D,R G.J. Schulz, "Resonances in Electron Impact on Atoms," *Rev. Mod. Phys.* Vol. 45, pg. 378 (1973).
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Tabular Data C-1.1.
Total Scattering of Electrons
(Inelastic and Elastic) in Gases

(H, H₂, and He)

e + H → e + H

e + H₂ → e + H₂

e + He → e + He

Energy (eV)	Cross Section (cm ²)		
	<u>H</u>	<u>H₂</u>	<u>He</u>
1.0 E 00		1.31 E-15	5.93 E-16
2.0 E 00		1.51 E-15	5.93 E-16
3.0 E 00		1.58 E-15	5.80 E-16
4.0 E 00	1.04 E-15	1.49 E-15	5.48 E-16
6.0 E 00	8.19 E-16	1.29 E-15	4.87 E-16
8.0 E 00	6.58 E-16	1.09 E-15	4.32 E-16
1.0 E 01	5.41 E-16	9.40 E-16	3.92 E-16
1.5 E 01		7.04 E-16	3.11 E-16
2.0 E 01		5.66 E-16	2.62 E-16
2.5 E 01		4.90 E-16	2.27 E-16
3.0 E 01		4.40 E-16	2.03 E-16
4.0 E 01		3.70 E-16	1.90 E-16
6.0 E 01		2.65 E-16	1.69 E-16
8.0 E 01		1.84 E-16	1.42 E-16
1.0 E 02		1.47 E-16	1.19 E-16
2.0 E 02		1.18 E-16	8.27 E-17
3.0 E 02		6.90 E-17	4.78 E-17
4.0 E 02		5.00 E-17	3.70 E-17

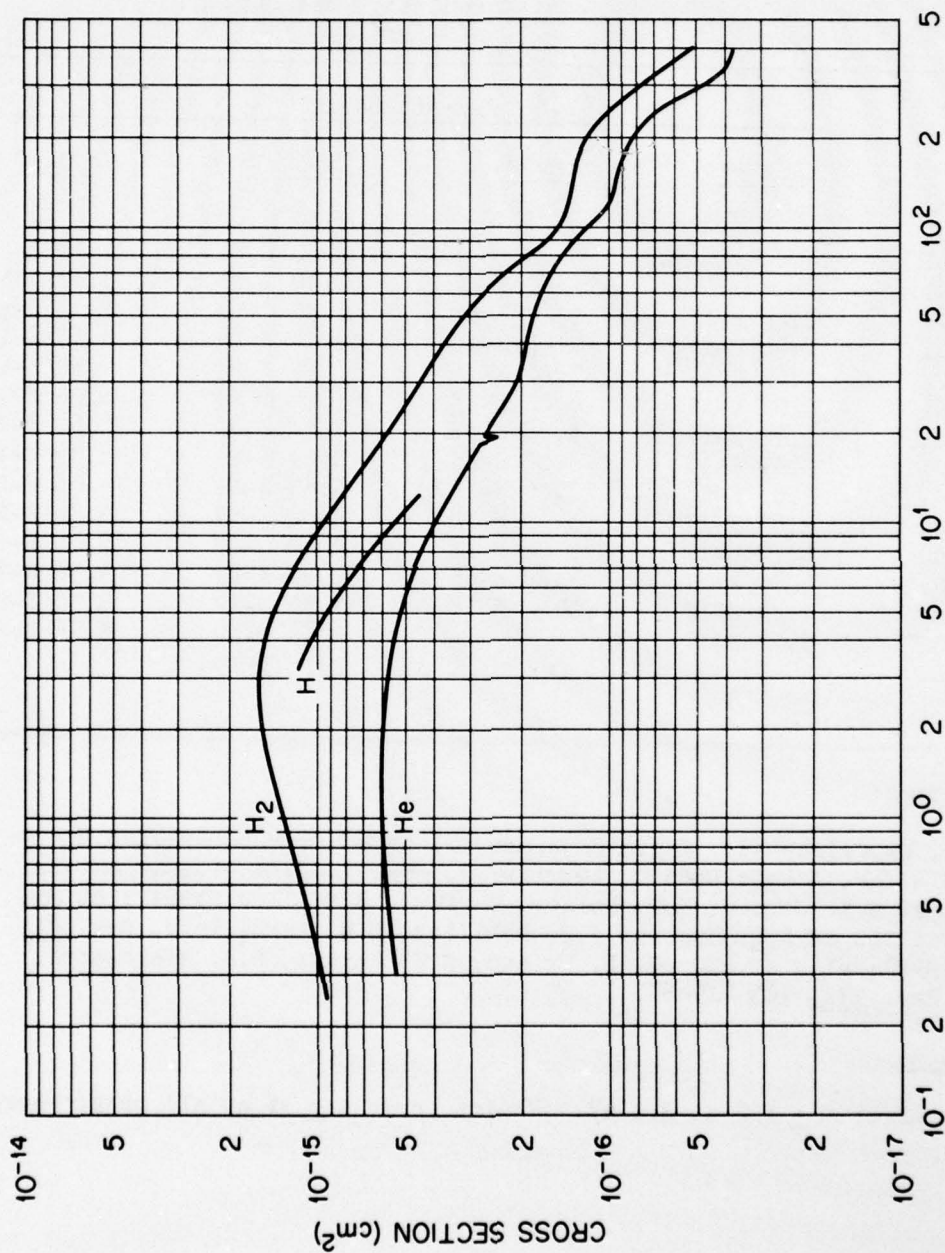
References:

e + H, Experimental: Best fit to experimental data as deduced by L.J. Kieffer, Atomic Data 2, 293 (1971).

e + H₂, Experimental: D.E. Golden, H.W. Bandel, and J.A. Salerno, Phys. Rev. 146, 40 (1966). C.E. Normand, Phys. Rev. 35, 1217 (1930).

e + He, Experimental: D.E. Golden and H.W. Bandel, Phys. Rev. 138, A14 (1965). C.E. Normand, Phys. Rev. 35, 1217 (1930).

Accuracy: e + H - not specific. e + H₂ - random and systematic errors < ± 3%.
e + He - random and systematic errors < ± 3%.



Graphical Data C-1.2.
Total scattering of electrons (inelastic and elastic) in gases

Tabular Data C-1.3.

Elastic Differential (in angle) scattering of electrons in He



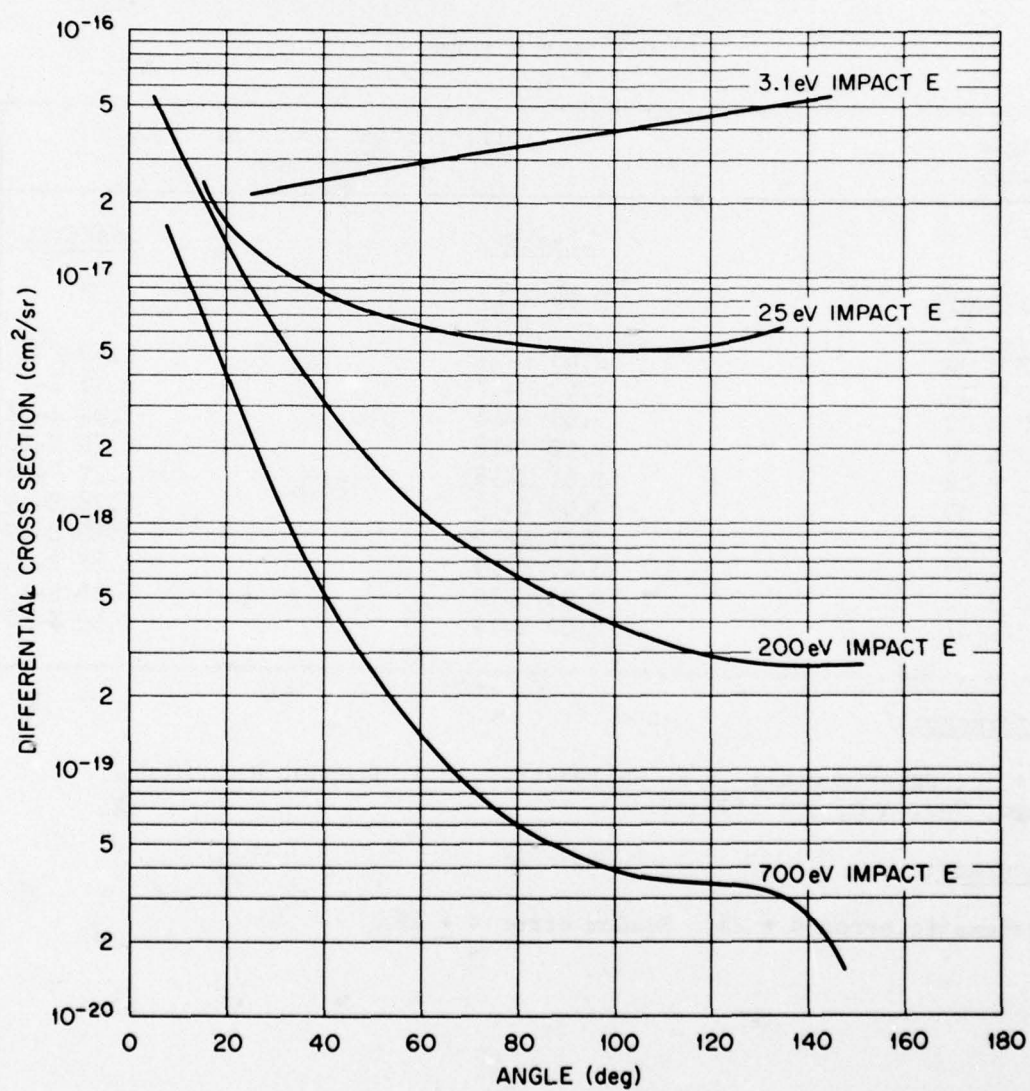
Angle (deg)	Differential Cross Section (cm ² /sr)			
	Impact Energy			
	3.1 eV	25 eV	200 eV	700 eV
5.0 E 00			5.42 E-17	
1.0 E 01			3.61 E-17	1.28 E-17
2.0 E 01		1.62 E-17	1.40 E-17	3.50 E-18
3.0 E 01	2.24 E-17	1.10 E-17	6.30 E-18	1.31 E-18
4.0 E 01	2.48 E-17	8.60 E-18	3.14 E-18	5.10 E-19
5.0 E 01	2.69 E-17	7.20 E-18	1.75 E-18	2.50 E-19
6.0 E 01	2.92 E-17	6.20 E-18	1.16 E-18	1.36 E-19
7.0 E 01	3.15 E-17	5.68 E-18	8.07 E-19	8.80 E-20
8.0 E 01	3.39 E-17	5.30 E-18	6.04 E-19	6.06 E-20
9.0 E 01	3.61 E-17	5.10 E-18	4.85 E-19	4.68 E-20
1.0 E 02	3.89 E-17	5.00 E-18	3.82 E-19	3.92 E-20
1.1 E 02	4.17 E-17	5.07 E-18	3.28 E-19	3.55 E-20
1.2 E 02	4.46 E-17	5.36 E-18	2.90 E-19	3.32 E-20
1.3 E 02	4.79 E-17	5.82 E-18	2.70 E-19	3.30 E-20
1.4 E 02	5.21 E-17		2.68 E-19	2.56 E-20
1.5 E 02			2.68 E-19	
1.6				

References:

$e + \text{He}$, Experimental: These data are all taken from the review by L.J. Kieffer, Atomic Data 2, 293 (1971). The individual sources are: - at 3.1 eV J.R. Gibson, K.T. Dolder, J. Phys. B 2, 1180 (1969); at 25, 200, and 700 eV A.L. Hughes, J.H. McMiller, G.M. Webb, Phys. Rev. 41, 154 (1932); also at 200 eV, L. Vriens, C.E. Kuyatt, S.R. Mielczarek, Phys. Rev. 170, 163 (1968).

Accuracy:

Random error < $\pm 15\%$ at 3.1 eV. Random error < $\pm 3\%$ at all other energies.



Graphical Data C-1.4.

Elastic differential (in angle) scattering of electrons
in $\text{He } e + \text{He} \rightarrow e + \text{He}$.

Tabular Data C-1.5.

Differential (In Angle) Cross Sections for
Inelastic and Elastic Scattering
of Electrons in He at 25 keV Impact Energy
 $e + \text{He} \rightarrow e + \text{He}$

Angle (deg)	Differential Cross Sections (cm ² /sr)	
	<u>Elastic</u>	<u>Inelastic</u>
1.0 E-01	2.04 E-17	
5.0 E-01	1.94 E-17	
1.0 E 00	1.65 E-17	1.42 E-16
2.0 E 00	1.03 E-17	2.40 E-17
3.0 E 00	5.60 E-18	7.24 E-18
4.0 E 00	2.90 E-18	2.70 E-18
5.0 E 00	1.61 E-18	1.17 E-18
6.0 E 00	9.09 E-19	5.78 E-19
7.0 E 00	5.21 E-19	3.10 E-19
8.0 E 00	3.20 E-19	1.85 E-19
9.0 E 00	2.25 E-19	1.18 E-19
1.0 E 01	2.00 E-19	7.52 E-20

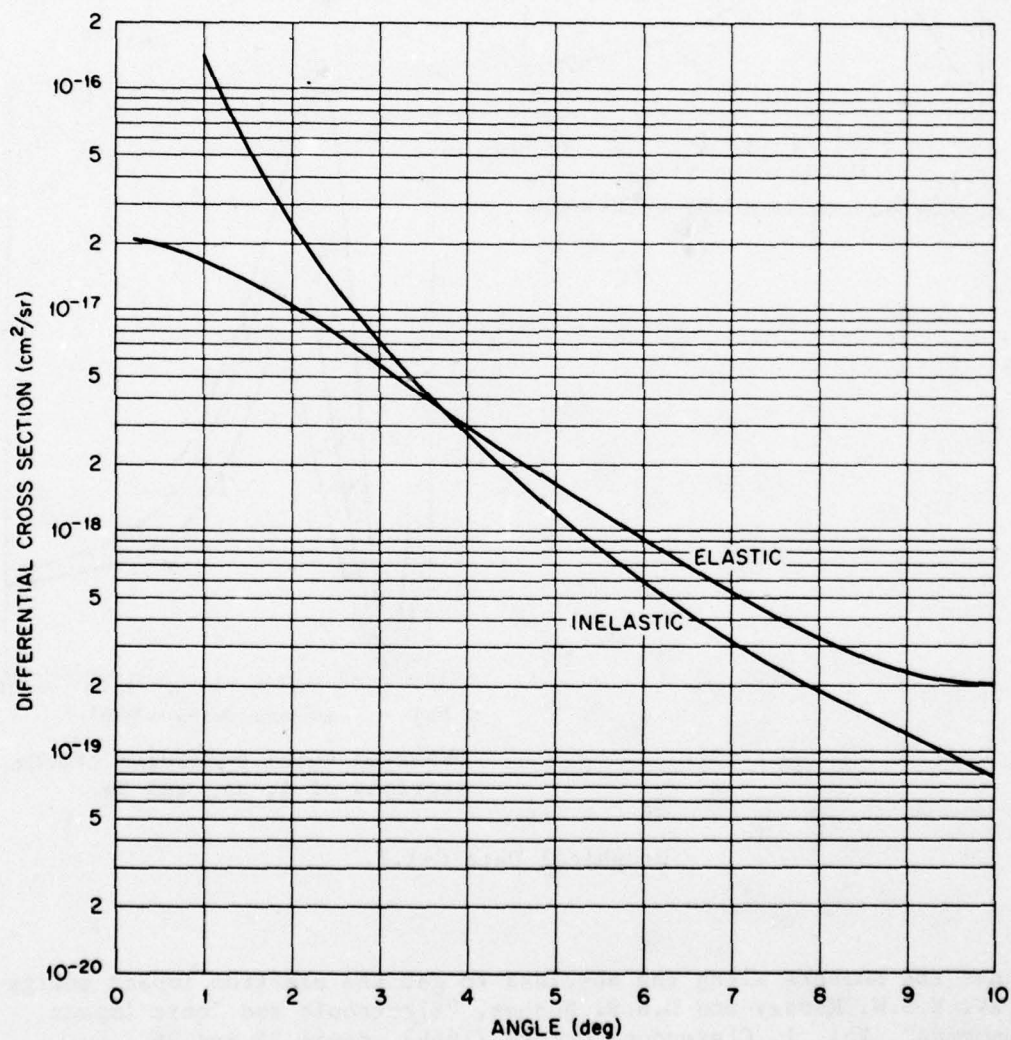
Reference:

$e + \text{He}$, Experimental: H.F. Wellenstein, R.A. Bonham, R.C. Ulsh,
Phys. Rev. A 8, 304 (1973).

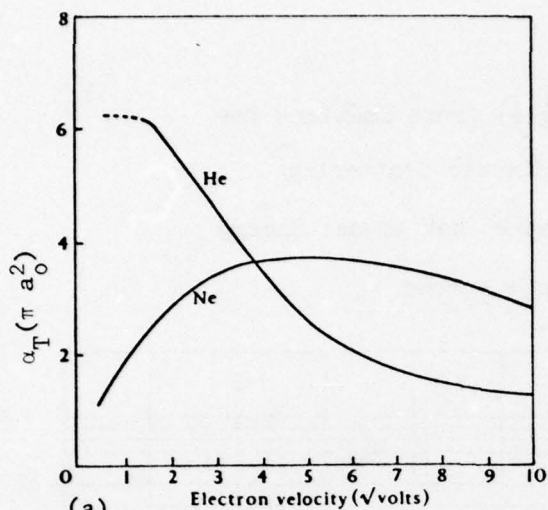
Accuracy:

Systematic error < ± 2%. Random error < ± 2%.

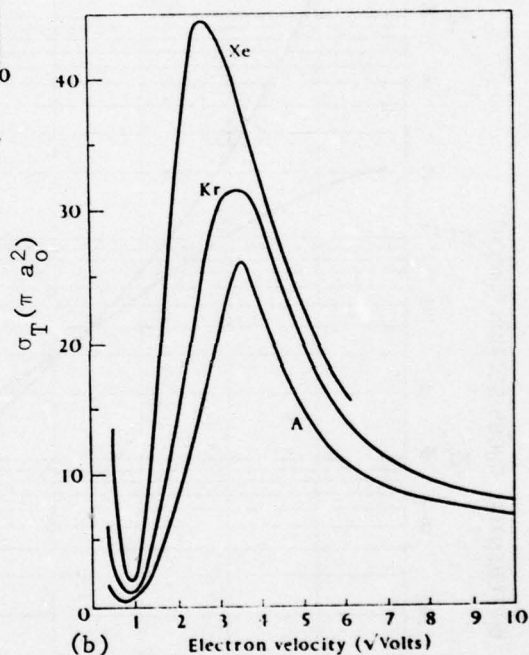
Differential (In Angle) Cross Sections for
Inelastic and Elastic Scattering
of Electrons in He at 25 keV Impact Energy



Graphical Data C-1.6.



(a) Observed total collision cross-sections of He and Ne.



(b) Observed total collision cross-sections of A, Kr, and Xe.

Graphical Data C-1.7.

Square the numbers along the abscissa to get the electron impact energy in eV. H.S.W. Massey and E.H.S. Burhop, "Electronic and Ionic Impact Phenomena", Vol. 1, Clarendon, Oxford (1969), pages 25 and 26.

(The data shown in C-1.8. are preferred)

Tabular Data C-1.8.

Total scattering cross sections for electrons on Ne, Ar, Kr, and Xe. Data taken from L.J. Kieffer, "A Compilation of Electron Collision Cross Section Data for Modeling Gas Discharge Lasers," JILA Information Center Report

No. 13, Sept. (1973).

	E (eV)	σ_T (cm ²)	E (eV)	σ_T (cm ²)	E (eV)	σ_T (cm ²)
Ne	.3707	1.055x10 ⁻¹⁶	1.589	1.9 x10 ⁻¹⁶	6.877	3.03 x10 ⁻¹⁶
	.4710	1.200x10 ⁻¹⁶	2.605	2.07 x10 ⁻¹⁶	8.790	3.235x10 ⁻¹⁶
	.6109	1.341x10 ⁻¹⁶	2.729	2.32 x10 ⁻¹⁶	11.19	3.42 x10 ⁻¹⁶
	.8091	1.477x10 ⁻¹⁶	3.373	2.47 x10 ⁻¹⁶	14.89	3.58 x10 ⁻¹⁶
	1.022	1.600x10 ⁻¹⁶	4.246	2.633x10 ⁻¹⁶	18.71	3.604x10 ⁻¹⁶
	1.245	1.800x10 ⁻¹⁶	5.395	2.82 x10 ⁻¹⁶	20.32	3.604x10 ⁻¹⁶
Ar	.1067	1.266x10 ⁻¹⁶	.4653	3.14 x10 ⁻¹⁷	5.124	8.331x10 ⁻¹⁶
	.1461	7.113x10 ⁻¹⁷	.6171	5.32 x10 ⁻¹⁷	5.786	9.731x10 ⁻¹⁶
	.1792	4.9 x10 ⁻¹⁷	.6934	7.45 x10 ⁻¹⁷	6.352	1.123x10 ⁻¹⁵
	.1976	3.6 x10 ⁻¹⁷	.8264	9.943x10 ⁻¹⁷	7.841	1.38 x10 ⁻¹⁵
	.2199	2.677x10 ⁻¹⁷	1.013	1.485x10 ⁻¹⁶	9.831	1.792x10 ⁻¹⁵
	.2572	1.55 x10 ⁻¹⁷	1.511	2.33 x10 ⁻¹⁶	10.71	1.87 x10 ⁻¹⁵
	.2950	1.606x10 ⁻¹⁷	1.635	2.373x10 ⁻¹⁶	12.18	1.98 x10 ⁻¹⁵
	.3328	1.836x10 ⁻¹⁷	2.481	4.058x10 ⁻¹⁶	13.59	1.974x10 ⁻¹⁵
	.3706	2.180x10 ⁻¹⁷	3.586	5.696x10 ⁻¹⁶	14.96	1.908x10 ⁻¹⁵
Kr	.1780	5.304x10 ⁻¹⁶	.6170	5.0 x10 ⁻¹⁷	2.928	7.497x10 ⁻¹⁶
	.2830	2.093x10 ⁻¹⁶	.7580	8.0 x10 ⁻¹⁷	5.313	1.88 x10 ⁻¹⁵
	.3270	1.45 x10 ⁻¹⁶	.9380	9.0 x10 ⁻¹⁷	7.958	2.620x10 ⁻¹⁵
	.4600	7.5 x10 ⁻¹⁷	1.000	1.07 x10 ⁻¹⁶	11.08	2.75 x10 ⁻¹⁵
	.5640	5.5 x10 ⁻¹⁷				
Xe	.1590	1.608x10 ⁻¹⁵	.7230	1.1 x10 ⁻¹⁶	2.870	1.8 x10 ⁻¹⁵
	.3650	3.573x10 ⁻¹⁶	.8240	1.25 x10 ⁻¹⁶	3.893	2.87 x10 ⁻¹⁵
	.4970	1.25 x10 ⁻¹⁶	1.199	2.936x10 ⁻¹⁶	5.345	3.9 x10 ⁻¹⁵
	.6520	1.021x10 ⁻¹⁶	1.654	6.2 x10 ⁻¹⁶	8.015	3.75 x10 ⁻¹⁵

Primary references: Ne- A. Salop and H.H. Nakano, Phys. Rev. A 2, 127 (1970). Ar- D.E. Golden and H.W. Bandel, Phys. Rev. 149, 58 (1966). Kr and Xe- C. Ramsauer, Ann. Physique 72, 345 (1923); C. Ramsauer and R. Kollath, Ann. Physik 3, 536 (1929).

Tabular Data C-1.9.

(a) Total Elastic Scattering Cross Sections for Electrons (σ_e) in Units of 10^{-16} cm^2										
	1keV	2keV	4keV	8keV	16keV	32keV	64keV	128keV	256keV	
He	4.23×10^{-2}	2.12×10^{-2}	1.07×10^{-2}	5.40×10^{-3}	2.76×10^{-3}	1.44×10^{-3}	7.86×10^{-4}	4.58×10^{-4}	2.97×10^{-4}	
Ne	4.88×10^{-1}	2.94×10^{-1}	1.66×10^{-1}	8.98×10^{-2}	4.76×10^{-2}	2.53×10^{-2}	1.39×10^{-2}	8.15×10^{-3}	5.29×10^{-3}	
Ar	1.36	8.75×10^{-1}	5.36×10^{-1}	3.12×10^{-1}	1.74×10^{-1}	9.59×10^{-2}	5.36×10^{-2}	3.17×10^{-2}	2.07×10^{-2}	
Kr	1.87	1.29	8.59×10^{-1}	5.53×10^{-1}	3.42×10^{-1}	2.05×10^{-1}	1.22×10^{-1}	7.47×10^{-2}	4.97×10^{-2}	
Xe	2.79	2.00	1.39	9.33×10^{-1}	6.04×10^{-1}	3.79×10^{-1}	2.35×10^{-1}	1.50×10^{-1}	1.02×10^{-1}	
F	5.10×10^{-1}	2.99×10^{-1}	1.66×10^{-1}	8.84×10^{-2}	4.65×10^{-2}	2.47×10^{-2}	1.35×10^{-2}	7.92×10^{-3}	5.14×10^{-3}	
(b) Momentum Transfer Cross Sections for Electrons (σ_m) in Units of 10^{-16} cm^2										
	1keV	2keV	4keV	8keV	16keV	32keV	64keV	128keV	256keV	
He	4.72×10^{-3}	1.39×10^{-3}	4.01×10^{-4}	1.14×10^{-4}	3.25×10^{-5}	9.24×10^{-6}	2.66×10^{-6}	7.92×10^{-7}	2.49×10^{-7}	
Ne	8.03×10^{-2}	2.64×10^{-2}	8.19×10^{-3}	2.43×10^{-3}	7.08×10^{-4}	2.05×10^{-4}	5.08×10^{-5}	1.80×10^{-5}	5.71×10^{-6}	
Ar	1.83×10^{-1}	6.57×10^{-2}	2.21×10^{-2}	7.00×10^{-3}	2.12×10^{-3}	6.30×10^{-4}	1.87×10^{-4}	5.67×10^{-5}	1.81×10^{-5}	
Kr	3.91×10^{-1}	1.60×10^{-1}	5.98×10^{-2}	2.09×10^{-2}	6.94×10^{-3}	2.21×10^{-3}	6.90×10^{-4}	2.17×10^{-4}	7.06×10^{-5}	
Xe	5.89×10^{-1}	2.59×10^{-1}	1.03×10^{-1}	3.79×10^{-2}	1.32×10^{-2}	4.46×10^{-3}	1.46×10^{-3}	4.78×10^{-4}	1.60×10^{-4}	
F	6.97×10^{-2}	2.25×10^{-2}	6.87×10^{-3}	2.03×10^{-3}	5.87×10^{-4}	1.69×10^{-4}	4.93×10^{-5}	1.48×10^{-5}	4.68×10^{-6}	

Calculated differential elastic electron scattering cross sections for 24 selected elements are presented in tabular form in the energy range 1 to 256 keV at values of 2π keV. The total elastic and momentum-transfer cross sections are tabulated also. Parameters for 12-parameter analytic fits to the differential values are given for 80 elements in a second table. The calculations were done in the relativistic static approximation with relativistic atomic wavefunctions for the heavier elements ($Z > 35$).

Marlo E. Riley, Crawford J. MacCallum, and Frank Biggs, "Theoretical Electron-Atom Elastic Scattering Cross Sections," Atomic Data and Nuclear Data Tables 15, 443-476(1975).



C-1.10. Graphical Data.

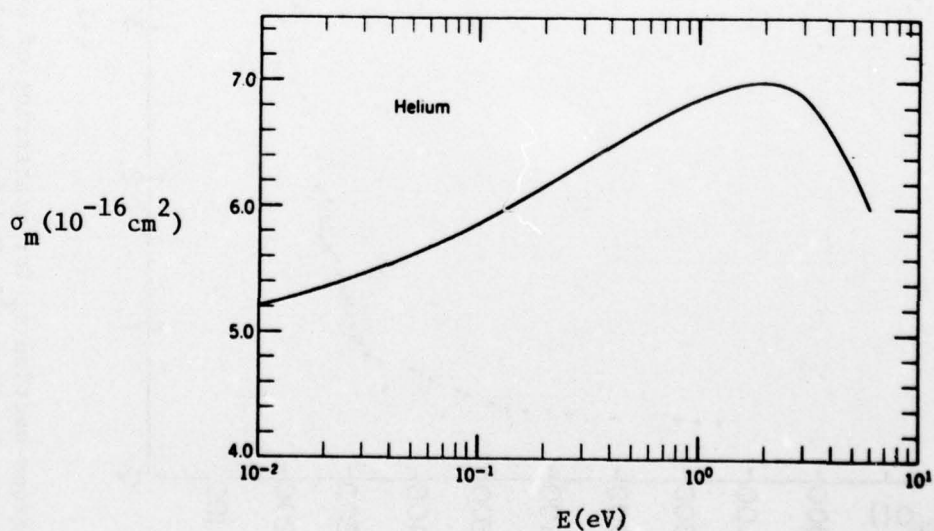
Total cross section σ_T for scattering of electrons by a mixture of 3P_0 and 3P_2 metastable argon atoms. R. Celotta, H. Brown, R. Molof, and B. Bederson, Phys. Rev. A 3, 1622 (1971).

Tabular and Graphical Data C-1.11.

Momentum transfer cross section in helium

Values up to 3 eV taken from the compilation in Chapter 14 of the book by Huxley and Crompton. Values at higher energies taken from H.B. Milloy and R.W. Crompton, Phys. Rev. A. 15, 1847 (1977).

E (eV)	σ_m (10^{-16} cm^2)	E (eV)	σ_m (10^{-16} cm^2)	E (eV)	σ_m (10^{-16} cm^2)
0.008	5.18	0.50	6.59	5.00	6.31
0.010	5.21	0.70	6.73	6.00	6.00
0.020	5.35	0.80	6.77	7.00	5.68
0.030	5.46	1.0	6.85	8.00	5.35
0.050	5.62	1.5	6.96	9.00	5.03
0.080	5.79	2.0	6.99	10.00	4.72
0.10	5.86	2.5	6.96	11.00	4.44
0.20	6.16	3.0	6.89	12.00	4.15
0.30	6.35	4.00	6.62		

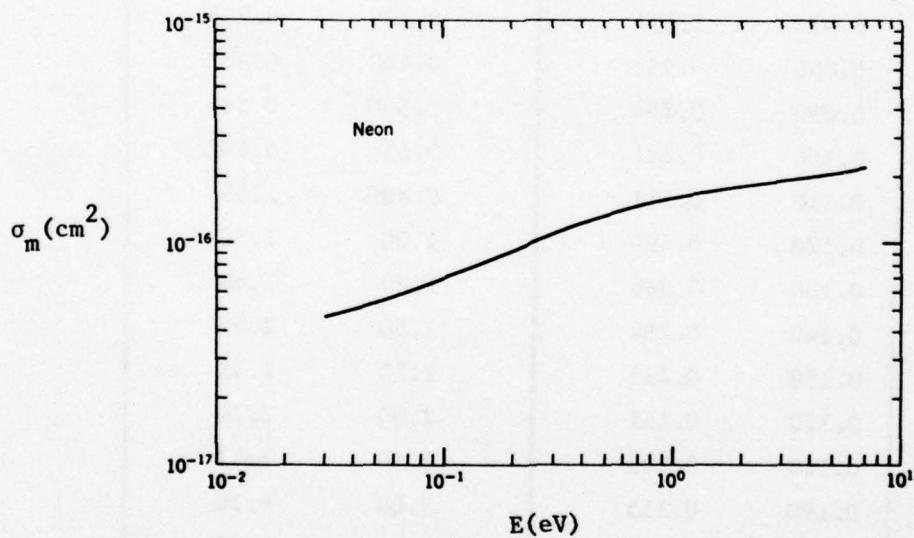


Tabular and Graphical Data C-1.12.

Values taken from the compilation in Chapter 14 of the book by Huxley and Crompton.

Momentum transfer cross section for electrons in neon

E (eV)	σ_m (10^{-16} cm^2)	E (eV)	σ_m (10^{-16} cm^2)
0.03	0.469	0.80	1.528
0.05	0.536	0.90	1.580
0.08	0.636	1.00	1.619
0.10	0.701	1.50	1.753
0.15	0.828	2.00	1.815
0.25	1.018	3.00	1.906
0.40	1.225	4.00	1.984
0.50	1.321	5.00	2.070
0.60	1.402	6.00	2.144
0.70	1.472	7.00	2.213

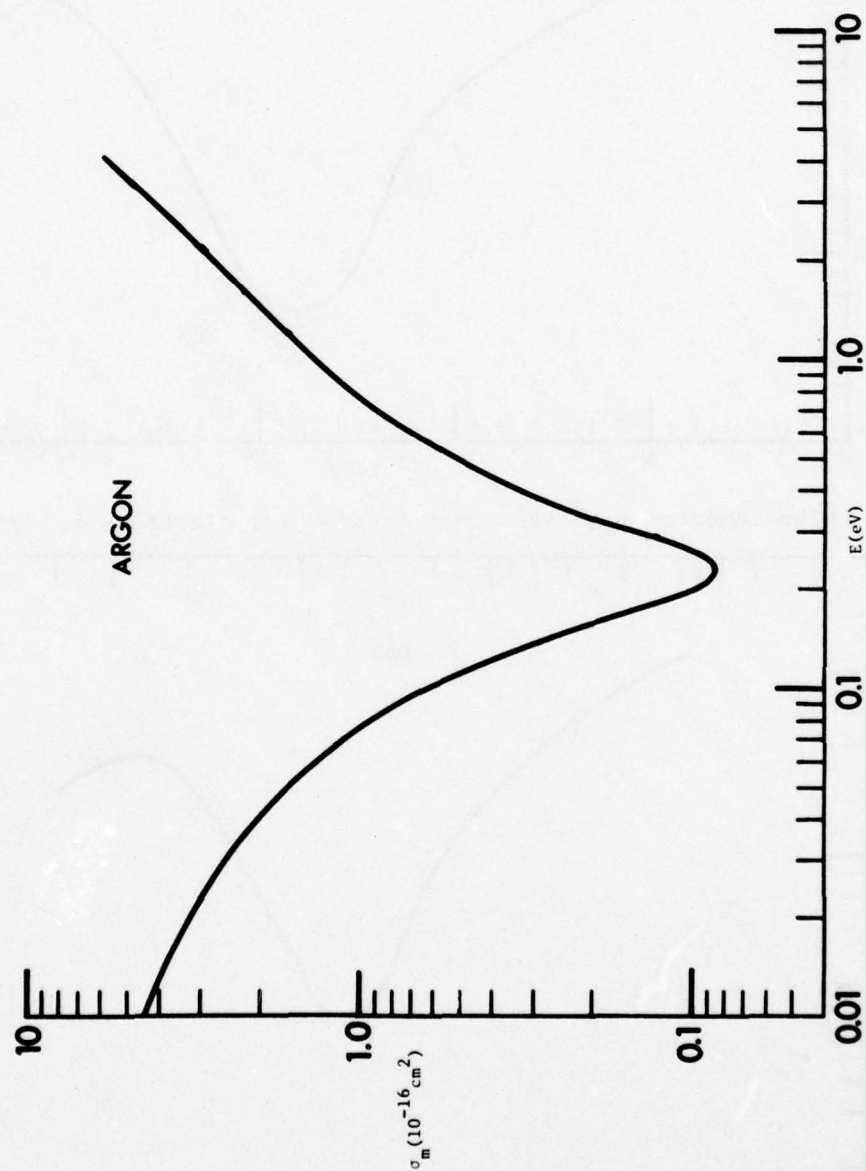


Tabular Data C-1.13.

Taken from H.B. Milloy, R.W. Crompton, J.A. Rees, and A.G. Robertson,
Aust. J. Phys. 30, 61 (1977).

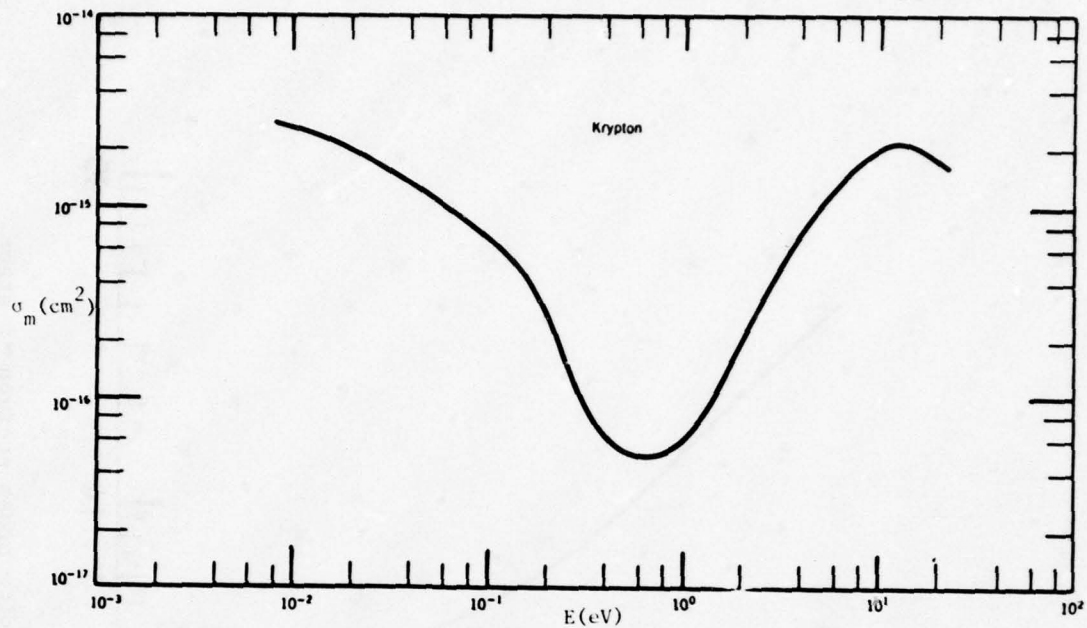
Momentum transfer cross section in argon

E(eV)	$\sigma_m (10^{-16} \text{ cm}^2)$	E(eV)	$\sigma_m (10^{-16} \text{ cm}^2)$
0.014	3.88	0.210	0.092
0.017	3.56	0.220	0.086
0.020	3.28	0.230	0.085
0.025	2.89	0.240	0.087
0.030	2.57	0.250	0.091
0.035	2.29	0.260	0.098
0.040	2.05	0.280	0.120
0.050	1.662	0.300	0.151
0.060	1.357	0.320	0.188
0.070	1.114	0.325	0.206
0.080	0.916	0.400	0.317
0.090	0.754	0.500	0.504
0.100	0.621	0.650	0.792
0.110	0.511	0.800	1.05
0.120	0.420	1.00	1.37
0.130	0.348	1.20	1.66
0.140	0.284	1.50	2.05
0.150	0.233	1.70	2.33
0.170	0.161	2.00	2.70
0.180	0.135	2.50	3.43
0.190	0.115	3.00	4.20
0.200	0.101	4.00	5.70

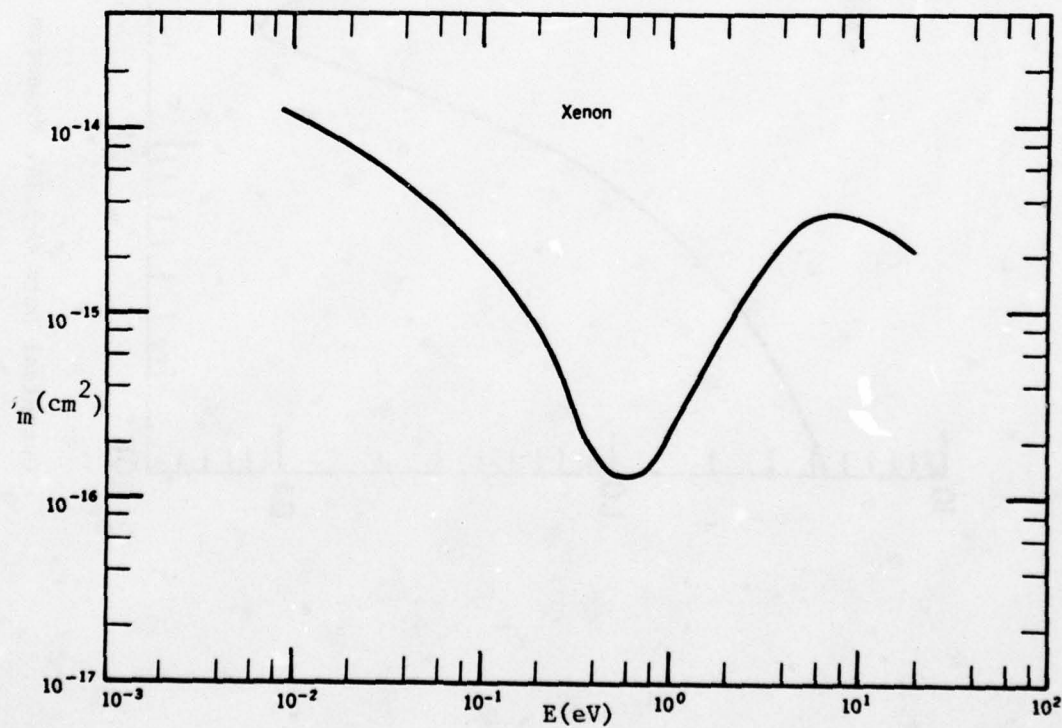


Graphical Data C-1.14. Momentum transfer cross section in argon.

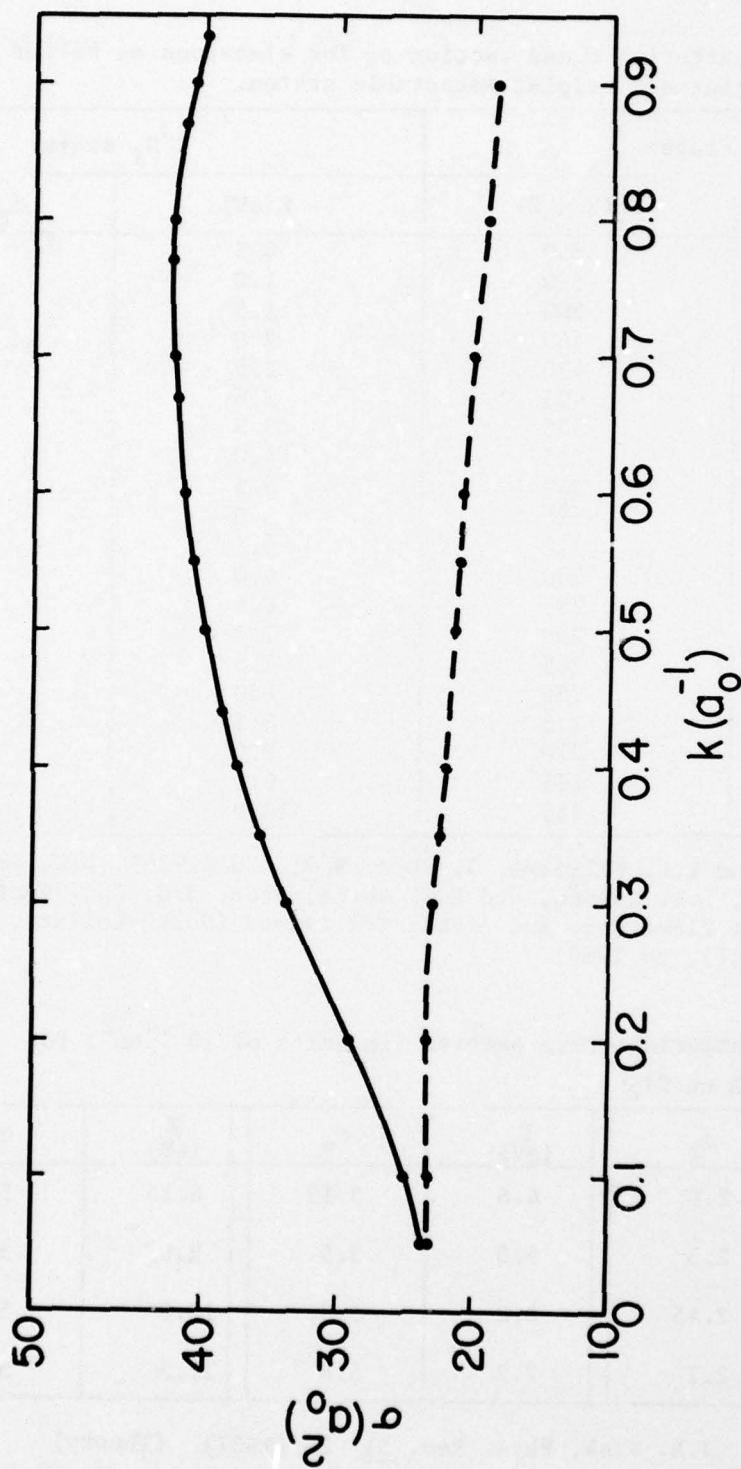
(a) The momentum transfer cross section for electrons in krypton.



(b) The momentum transfer cross section for electrons in xenon.



(From L.S. Frost and A.V. Phelps, Phys. Rev., 136, A1538, 1964).
Graphical Data C-1.15.



Graphical Data C-1.16.

Total elastic cross section for $e + F_2$ scattering (solid curve- F_2^- core orbitals). Momentum transfer cross section for $e + F_2$ scattering (dashed curve- F_2^- core orbitals). Square k and multiply by 13.605 to get the electron impact energy in eV. B.I. Schneider and P.J. Hay, Phys. Rev. A13, 2049 (1976).

Tabular Data C-1.17.

(a) Total scattering cross section σ_T for electrons on helium in the singlet and triplet metastable states.

2^1S_0 state		2^3S_1 state	
E(eV)	$\sigma_T(\pi a_0^2)$	E(eV)	$\sigma_T(\pi a_0^2)$
0.5	850	0.5	659
1.0	620	1.0	568
1.5	500	1.5	426
2.0	460	2.0	329
2.5	430	2.5	284
3.0	405	3.0	267
3.5	375	3.5	250
4.0	355	4.0	227
4.5	340	4.5	216
5.0	325	5.0	199
5.5	310	5.5	193
6.0	300	6.0	188
6.5	295	6.5	182
7.0	290	7.0	176
7.5	285	7.5	171
8.0	280	8.0	164
8.5	275	8.5	160
9.0	270	9.0	153
9.5	265	9.5	148
10.0	260	10.0	148

W.G. Wilson and W.L. Williams, J. Phys. B 9, 423 (1976). R.H. Neynaber, S.M. Trujillo, L.L. Marino, and E.W. Rothe, Proc. 3rd. Int. Conf. on the Physics of Electronic and Atomic Collisions (North-Holland, Amsterdam (1964), pg 1089).

(b) Total scattering cross section (in units of 10^{-14} cm^2) for electrons on Cl_2

E (eV)	σ_T	E (eV)	σ_T	E (eV)	σ_T
2.2	2.9	4.6	3.15	8.15	5.8
2.7	2.5	5.0	3.5	9.05	5.6
3.2	2.45	6.2	5.3	10.3	5.2
4.05	2.7	7.2	5.8	11.3	5.0

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C-2. EXCITATION BY ELECTRON IMPACT

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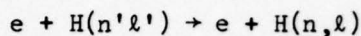
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C-2.1. Collisional excitation of H by electron impact:



At sufficiently high impact energies the excitation cross section is given by the Bethe formula:

$$Q_{n'l', nl} = 8.806 \times 10^{-17} (C_{n'l', nl} / E) \ln(D_{n'l', nl} E)$$

Here E is the electron impact energy; $C_{n'l', nl}$ and $D_{n'l', nl}$ are constants depend only on the quantum states involved. This equation is valid only for "optically allowed" transitions (i.e., $l-l' = 1$).

Given in the tables on the facing page are tabular values of the two constants for excitation events where the principal quantum number increases by one or two (i.e., $n-n' = 1$ or 2) and the angular momentum quantum number increases by one (i.e., $l-l' = 1$). When these constants are inserted in the above equation with the energy E in electron volts, then the cross section Q is given in units of cm^2 . The cross sections should be quite accurate at impact energies above 100 eV for $1s \rightarrow n l$ transitions and above 50 eV for all other transitions.

These theoretical values are by G. G. McCoyd and S. N. Milford, Phys. Rev. 130, 206 (1963). Note that the number in parenthesis denotes power of 10.

Tabular Data C-2.2.

Collision Excitation of H by Electron Impact $e + H(n'l') \rightarrow e + H(n,l)$

$C_{n'l',nl}$ for $n-n' = 1$

l'/n'	1	2	3	4	5	6	7
0	3.0(1)	1.70(2)	5.4(2)	1.32(3)	2.7(3)	5.0(3)	8.4(3)
1		2.7(2)	6.9(2)	1.47(3)	2.8(3)	4.8(3)	7.8(3)
2			1.14(3)	2.2(3)	3.8(3)	6.2(3)	9.5(3)
3				3.3(3)	5.3(3)	8.2(3)	1.22(4)
4					7.5(3)	1.10(4)	1.58(4)
5						1.48(4)	2.1(4)
6							2.7(4)
7							
8							
9							

$C_{n'l',nl}$ for $n-n' = 2$

0	4.8	3.0(1)	9.3(1)	2.2(2)	4.3(2)	7.7(2)	1.27(3)
1		3.5(1)	1.07(2)	2.3(2)	4.4(2)	7.4(2)	1.18(3)
2			1.20(2)	2.9(2)	5.5(2)	9.1(2)	1.42(3)
3				2.9(2)	6.4(2)	1.10(3)	1.71(3)
4					5.6(2)	1.19(3)	1.96(3)
5						9.7(2)	2.0(3)
6							1.54(3)
7							
8							
9							

$D_{n'l',nl}$ for $n-n' = 1$

l'/n'	1	2	3	4	5	6	7
0	1.03(-1)	2.7(-1)	5.0(-1)	8.0(-1)	1.14	1.6	2
1		5.8(-1)	7.6(-1)	1.08	1.44	1.9	3
2			1.39	1.50	1.77	2	3
3				2.6	2.6	2	4
4					4.2	5	4
5						5	5
6							1.2(1)
7							
8							
9							

$D_{n'l',nl}$ for $n-n' = 2$

0	1.41(-1)	3(-1)	5.2(-1)	8.1(-1)	1.2	1.8	1.8
1		8(-1)	9.7(-1)	1.2	2	1.8	1.8
2			2.7	2	3	3	4
3				5.9	4	5	4
4					1.1(1)	8	7
5						2(1)	1.3(1)
6							3(1)
7							
8							
9							

C-2.3. Collisional excitation of hydrogenic ions by electron impact:
(General Formulation)

Seaton (in Atomic and Molecular Processes, Ed. D.R. Bates, Academic Press, N.Y., 1962 p. 389) presents curves showing $1s \rightarrow 2s$ and $1s \rightarrow 2p$ excitation cross sections as a function of target nuclear charge for hydrogenic ions. Here Z is nuclear charge, Q is cross section in cm^2 , W is incident energy, and ΔE is the transition energy for the excitation process.

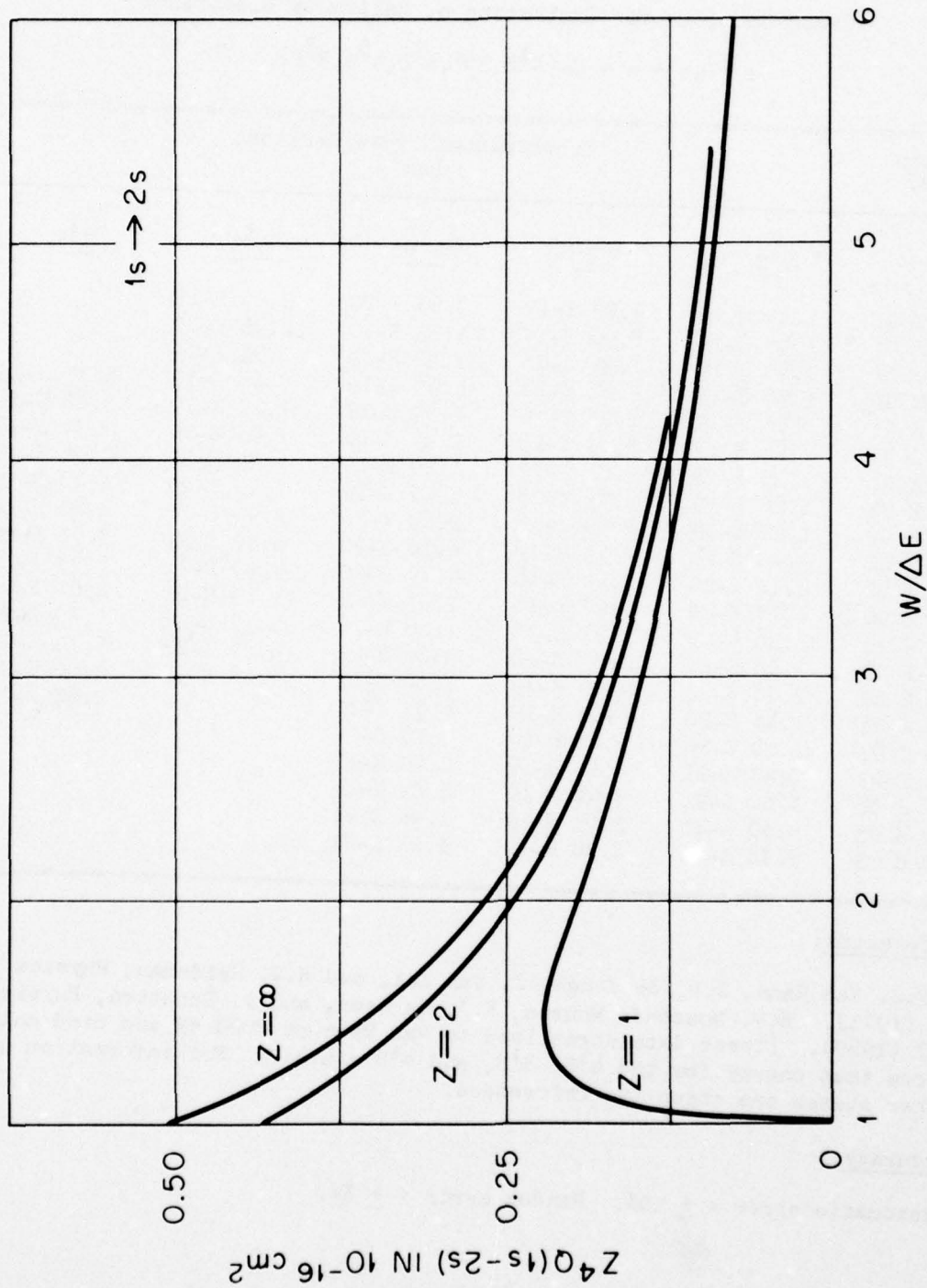
The results as presented here are of qualitative interest only, as the basic theoretical method (Born approximation) is inaccurate at the energy range covered here.

In general one may estimate a cross section for excitation of any hydrogenic ion at projectile impact energies five or more times threshold energy by the following procedure. Taking the cross section for excitation of the required state in H from either of the two preceding data tables:

- (i) Increase cross section values by a factor of Z^4 (where Z is the target nuclear charge).
- (ii) Increase energy scale by a factor of Z^2 .

Collisional Excitation of Hydrogenic Ions by Electron Impact:

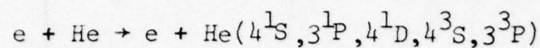
(General Formulation)



Graphical Data C-2.4.

Tabular Data C-2.5.

Cross Sections for Excitation of Helium by Electrons:



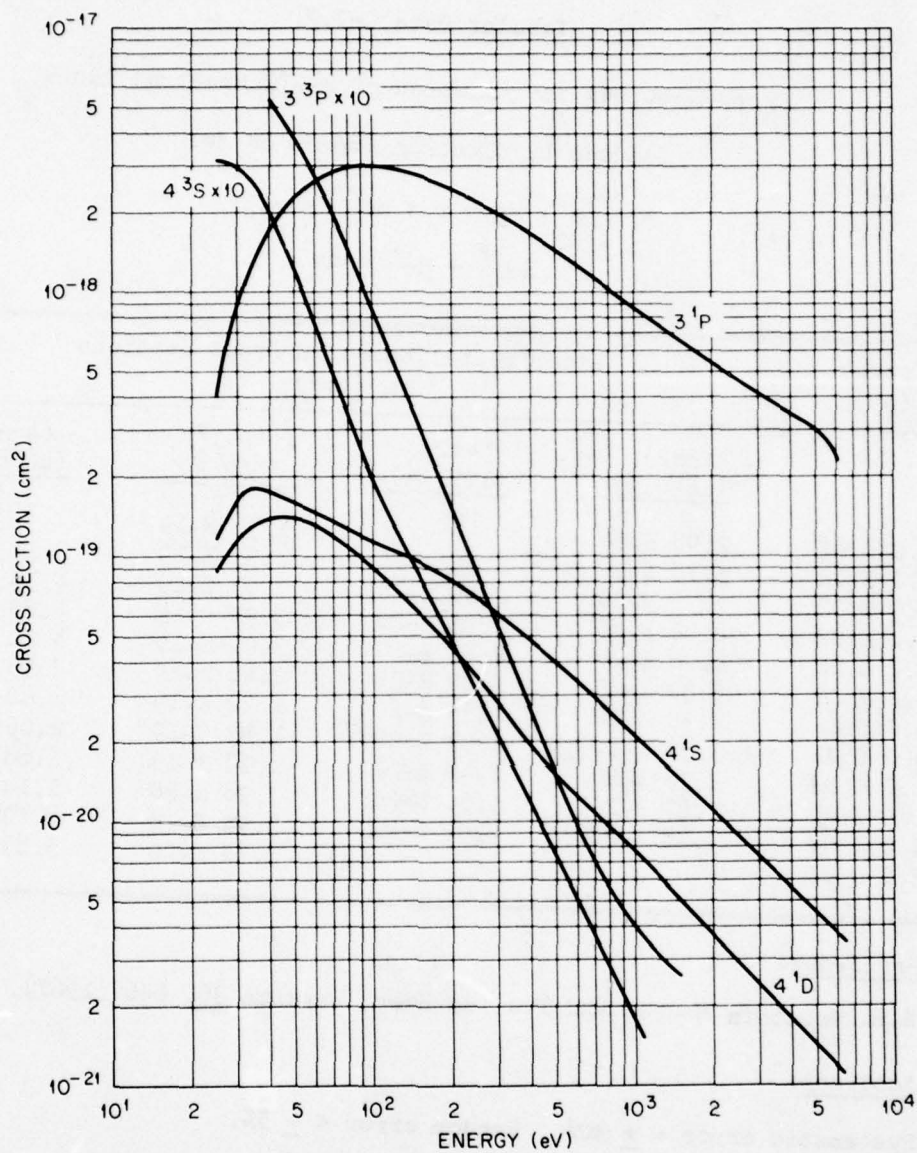
Energy (eV)	Experimental Cross Sections (cm ²)				
	<u>4¹S</u>	<u>3¹P</u>	<u>4¹D</u>	<u>4³S</u>	<u>3³P</u>
2.5 E 01	1.14 E-19	4.03 E-19	8.65 E-20	3.15 E-19	
3.0 E 01	1.63 E-19	8.90 E-19	1.13 E-19	2.96 E-19	
3.5 E 01	1.80 E-19	1.32 E-18	1.32 E-19	2.55 E-19	
4.0 E 01	1.76 E-19	1.67 E-18	1.38 E-19	2.01 E-19	5.17 E-19
5.0 E 01	1.58 E-19	2.23 E-18	1.39 E-19	1.20 E-19	3.80 E-19
6.0 E 01	1.46 E-19	2.60 E-18	1.31 E-19	7.45 E-20	2.71 E-19
7.0 E 01	1.35 E-19	2.81 E-18	1.20 E-19	4.84 E-20	2.00 E-19
8.0 E 01	1.26 E-19	2.94 E-18	1.09 E-19	3.40 E-20	1.48 E-19
1.0 E 02	1.12 E-19	2.99 E-18	9.00 E-20	1.90 E-20	8.20 E-20
1.5 E 02	9.40 E-20	2.75 E-18	6.10 E-20	8.40 E-21	3.01 E-20
2.0 E 02	8.10 E-20	2.44 E-18	4.45 E-20	4.70 E-21	1.49 E-20
4.0 E 02	4.75 E-20	1.67 E-18	1.95 E-20	1.13 E-21	2.60 E-21
6.0 E 02	3.38 E-20	1.27 E-18	1.26 E-20	5.15 E-22	1.00 E-21
8.0 E 02	2.58 E-20	1.03 E-18	9.60 E-21	2.80 E-22	5.70 E-22
1.0 E 03	2.08 E-20	8.70 E-19	7.80 E-21	1.78 E-22	4.00 E-22
1.5 E 03	1.44 E-20	6.60 E-19	4.95 E-21		2.62 E-22
2.0 E 03	1.10 E-20	5.40 E-19	3.75 E-21		
3.0 E 03	7.40 E-21	4.15 E-19	2.40 E-21		
4.0 E 03	5.60 E-21	3.48 E-19	1.81 E-21		
5.0 E 03	4.50 E-21	3.05 E-19	1.44 E-21		
6.0 E 03	3.78 E-21	2.40 E-19	1.17 E-21		

References:

A.F.J. Van Raan, J.D. de Jongh, J. Van Eck, and H.G. Heideman, Physica 53, 45 (1971). H.M. Moustafa Moussa, F.J. de Heer, and J. Schutten, Physica 40, 517 (1969). [These data normalized to Van Raan at 2000 eV and used only above that energy for the 4¹S, 3¹P, and 4¹D states.] For information on other states see these two references.

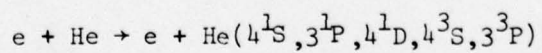
Accuracy:

Systematic error < ± 10%. Random error < ± 7%.



Graphical Data C-2.6.

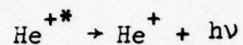
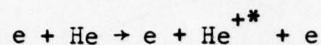
Cross Sections for Excitation of Helium by Electrons:



Tabular Data C-2.7.

Cross Sections for Emission of He II Spectral Lines

Induced by Electron Impact on He:



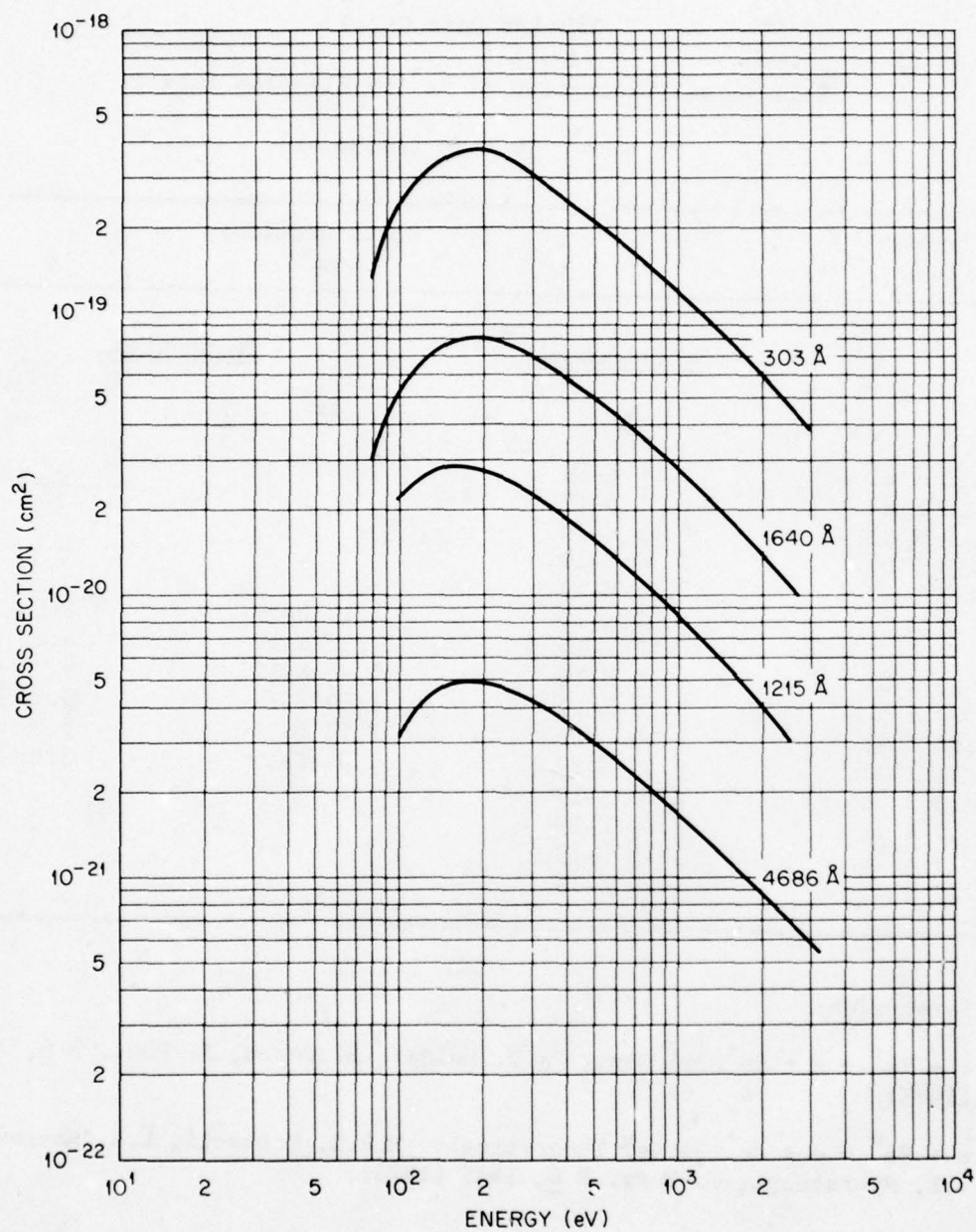
Energy (eV)	Experimental Emission Cross Sections (cm ²)			
	(3→2) (1640 Å)	(4→2) (1251 Å)	(2 ² P→1 ² S) (303 Å)	(4→3) (4686 Å)
8.0 E 01	2.98 E-20		1.36 E-19	
1.0 E 02	5.18 E-20	2.21 E-20	2.33 E-19	3.15 E-21
1.5 E 02	7.75 E-20	2.85 E-20	3.55 E-19	4.78 E-21
2.0 E 02	8.00 E-20	2.73 E-20	3.75 E-19	4.85 E-21
3.0 E 02	6.90 E-20	2.27 E-20	3.05 E-19	4.20 E-21
4.0 E 02	5.80 E-20	1.85 E-20	2.48 E-19	3.55 E-21
6.0 E 02	4.30 E-20	1.34 E-20	1.82 E-19	2.60 E-21
8.0 E 02	3.38 E-20	1.03 E-20	1.43 E-19	2.05 E-21
1.0 E 03	2.78 E-20	8.40 E-21	1.18 E-19	1.68 E-21
1.5 E 03	1.87 E-20	5.50 E-21	7.98 E-20	1.14 E-21
2.0 E 03	1.38 E-20	4.00 E-21	5.95 E-20	8.70 E-22
3.0 E 03			3.75 E-20	5.80 E-22

Reference:

H.R. Moustafa Moussa and F.J. de Heer, Physica 36, 646 (1967).

Accuracy:

Systematic error < ± 30%. Random error < ± 5%.



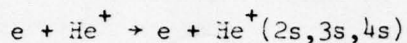
Graphical Data C-2.8.

Cross Sections for Emission of He II Spectral Lines

Induced by Electron Impact on He:

Tabular Data C-2.9.

Collisional Excitation of He^+ by Electron Impact:



Energy (eV)	Cross Sections (cm^2)		
	<u>Experimental</u> *		<u>Theoretical</u>
	<u>2s</u>	<u>3s</u>	<u>4s</u>
4.0 E 01	2.60 E-19		
4.2 E 01	6.35 E-19		
4.4 E 01	6.45 E-19		
4.6 E 01	6.50 E-19		
4.8 E 01	6.52 E-19		
5.0 E 01	6.50 E-19	1.15 E-19	3.60 E-20
5.5 E 01	6.40 E-19	1.32 E-19	4.29 E-20
6.0 E 01	6.15 E-19	1.42 E-19	4.70 E-20
8.0 E 01	5.18 E-19	1.59 E-19	5.66 E-20
1.0 E 02	4.65 E-19	1.57 E-19	5.70 E-20
2.0 E 02	3.55 E-19	1.04 E-19	3.83 E-20
4.0 E 02	2.66 E-19		
6.0 E 02	2.02 E-19		
8.0 E 02	1.46 E-19		
1.0 E 03	1.24 E-19		

References:

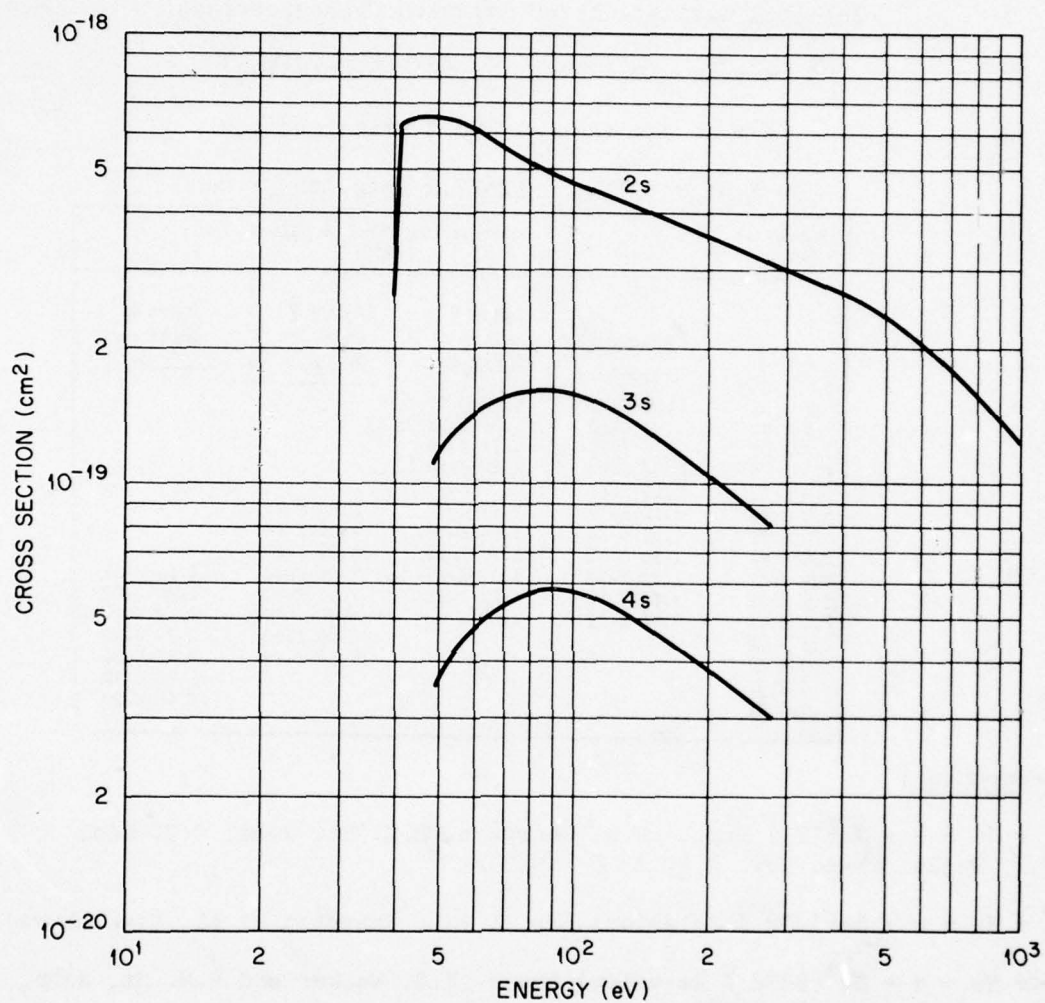
$e + \text{He}^+ \rightarrow e + \text{He}^+(2s)$ Exp.: K.T. Dolder, B. Peart, J. Phys. B 6, 2415 (1973).

$e + \text{He}^+ \rightarrow e + \text{He}^+(3s, 4s)$ Theoretical: M.R.C. McDowell, L.A. Morgan, V.P. Myerscough, J. Phys. B 6, 1435 (1973).

Accuracy:

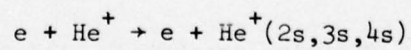
Random error < $\pm 10\%$.

*These data are the cross section for formation of the excited state by all mechanisms including direct excitation and also cascade from higher states. In this case cascade is believed to be an appreciable contribution to the total cross section.



Graphical Data C-2.10.

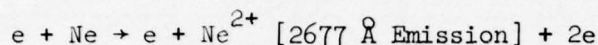
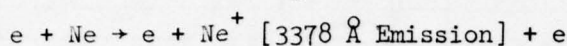
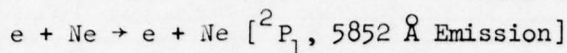
Collisional Excitation of He⁺ by Electron Impact:



Tabular Data C-2.11.

Excitation of Neon by Electrons.

Selected Excitation and Emission Cross Sections:



Energy (eV)	Experimental Cross Sections (cm ²)			
	² P ₁ State	5852 Å Emission (² P ₁ + ¹ S ₂)	3378 Å Emission (3p ² P _{1/2} +3s ² P _{1/2})	2677 Å Emission (3p ³ P+3s ³ S ⁰)
2.2 E 01	8.50 E-19	8.10 E-19		
2.8 E 01	1.53 E-18	1.62 E-18		
3.0 E 01	1.70 E-18	1.78 E-18		
4.0 E 01	2.30 E-18	2.20 E-18		
5.0 E 01	2.19 E-18	2.31 E-18		
6.0 E 01	2.10 E-18	2.23 E-18	2.30 E-20	
8.0 E 01	1.80 E-18	1.94 E-18	4.90 E-20	
1.0 E 02	1.56 E-18	1.70 E-18	6.29 E-20	
1.4 E 02	1.20 E-18	1.34 E-18	7.20 E-20	8.50 E-21
1.6 E 02	1.08 E-18	1.21 E-18	7.15 E-20	1.36 E-20
2.0 E 02	8.96 E-19	1.00 E-18	6.78 E-20	2.13 E-20
2.5 E 02			6.09 E-20	2.74 E-20
3.0 E 02			5.50 E-20	2.83 E-20
4.0 E 02				2.79 E-20
5.0 E 02				2.64 E-20

References:

$e + \text{Ne} \rightarrow e + \text{Ne}(^2P_1)$ Exp.: F.A. Sharpton, R.M. St. John, C.C. Lin, F.E. Fajen, Phys. Rev. A 2, 1305 (1970).

$e + \text{Ne} \rightarrow e + \text{Ne}(5852 \text{ \AA} \text{ Emission})$ Exp.: F.A. Sharpton et al. (see above).

$e + \text{Ne} \rightarrow e + \text{Ne}^+(3378 \text{ \AA} \text{ Emission})$ Exp.: K.G. Walker and R.M. St. John, Phys. Rev. A 6, 240 (1972).

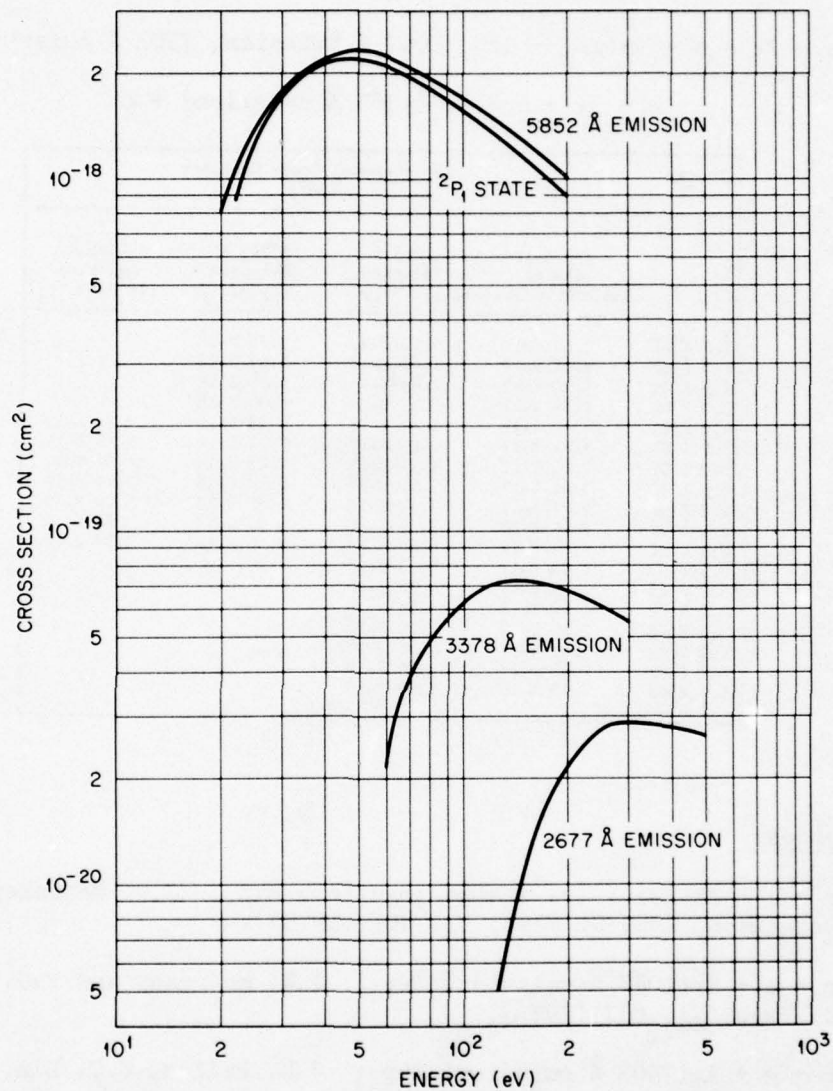
$e + \text{Ne} \rightarrow e + \text{Ne}^{2+}(2677 \text{ \AA} \text{ Emission})$ Exp.: Yu.M. Smirnov and Yu. D. Sharonov, Optics and Spectry. 32, 333 (1972).

Accuracy:

2677 Å Line - no accuracy limits specified. All others - systematic error < ± 10%; random error < ± 5%.

Notes:

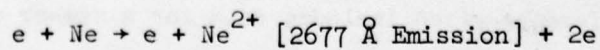
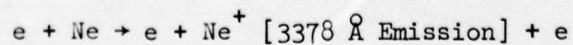
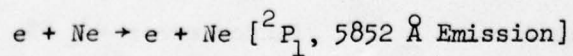
Notation used here for excited neutral rare gas atoms is the Paschen form. For identification in other notations see "Atomic Energy Levels" Volume 1, NBS Circular 467 (1949) by C.E. Moore.



Graphical Data C-2.12.

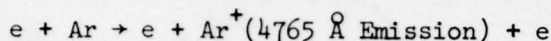
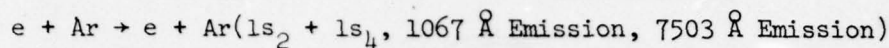
Excitation of Neon by Electrons.

Selected Excitation and Emission Cross Sections:



Tabular Data C-2.13.

Excitation of Argon by Electrons:



Energy (eV)	Experimental Cross Sections (cm ²)			
	1s ₂ & 1s ₄ States (Sum of Two States)	1067 Å Emission (1s ₄ +1p ₂)	7503 Å Emission (2p ₁ +1s ₂)	4765 Å Emission (4p ² P _{1/2} +4s ² P _{1/2})
1.5 E 01	2.50 E-17	9.20 E-18	9.38 E-18	
2.0 E 01	3.67 E-17	1.68 E-17	8.62 E-18	
2.5 E 01	4.20 E-17	2.09 E-17	7.38 E-18	
3.0 E 01	4.44 E-17	2.17 E-17	6.95 E-18	
4.0 E 01	4.40 E-17	1.44 E-17	6.88 E-18	1.70 E-19
5.0 E 01	4.21 E-17	1.23 E-17	7.22 E-18	4.46 E-19
6.0 E 01	4.00 E-17	1.11 E-17	7.22 E-18	4.87 E-19
8.0 E 01	3.61 E-17	9.99 E-18	6.82 E-18	5.04 E-19
1.0 E 02	3.27 E-17	9.04 E-18	6.30 E-18	5.00 E-19
1.5 E 02	2.65 E-17	7.39 E-18	5.30 E-18	3.88 E-19
2.0 E 02	2.24 E-17	6.20 E-18	4.60 E-18	3.28 E-19
2.5 E 02	1.93 E-17	5.35 E-18		
3.0 E 02	1.71 E-17	4.72 E-18		
4.0 E 02	1.40 E-17	3.86 E-18		
5.0 E 02	1.19 E-17	3.28 E-18		
6.0 E 02	1.03 E-17	2.86 E-18		
8.0 E 02	8.46 E-18	2.30 E-18		
1.0 E 03	7.10 E-18	1.92 E-18		

References:

$e + \text{Ar} \rightarrow e + \text{Ar}(1s_2 + 1s_4 \text{ states together})$ Exp.: J.W. McConkey and F.G. Donaldson, Can. J. Phys. 51, 867 (1973).

$e + \text{Ar} \rightarrow e + \text{Ar}(1067 \text{ \AA} \text{ emission})$ Exp.: J.W. McConkey and F.G. Donaldson, Can. J. Phys. 51, 867 (1973).

$e + \text{Ar} \rightarrow e + \text{Ar}(7503 \text{ \AA} \text{ emission})$ Exp.: J.K. Ballou, C.C. Lin, and F.E. Fajen, Phys. Rev. A 8, 1797 (1973).

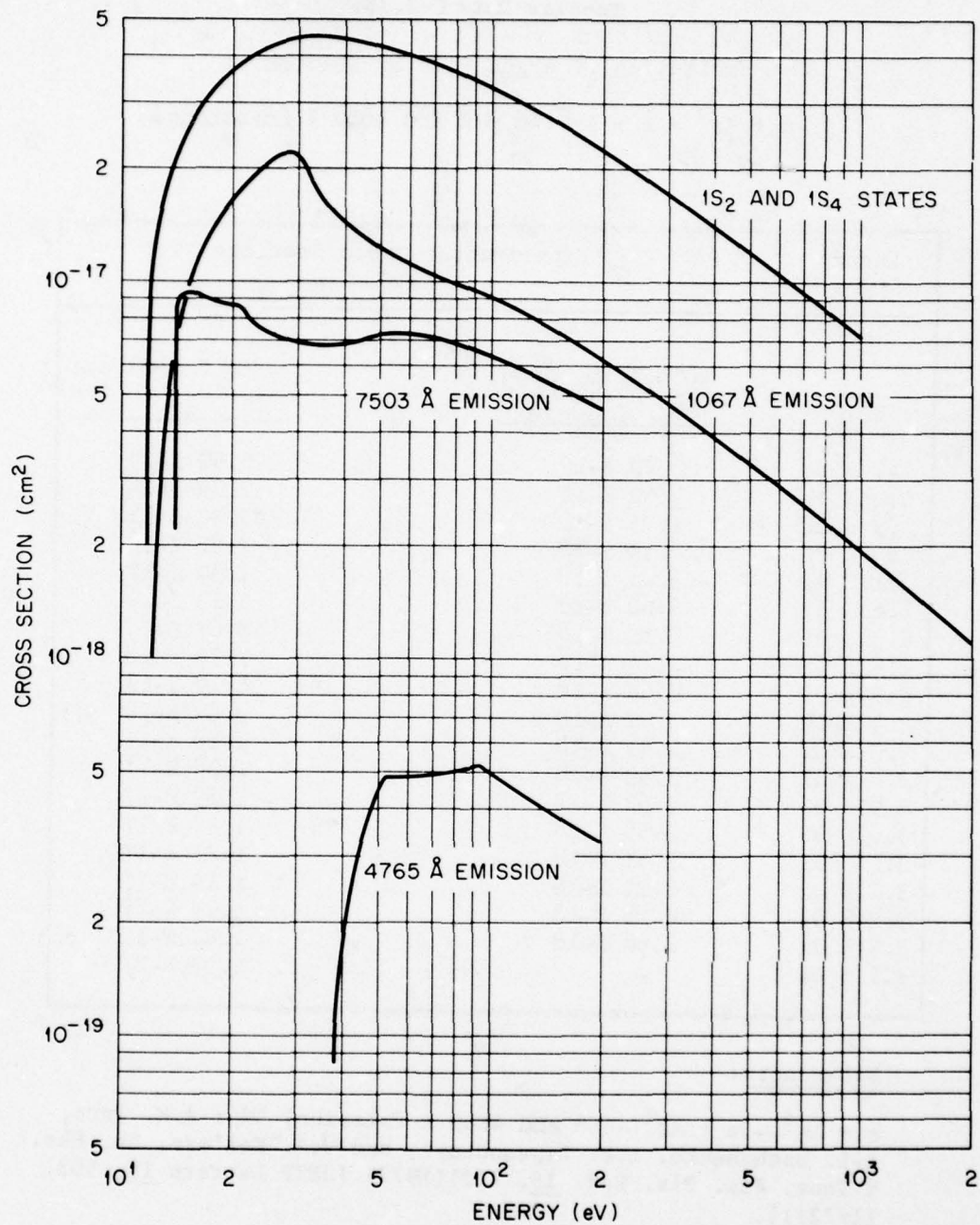
$e + \text{Ar} \rightarrow e + \text{Ar}^+(4765 \text{ \AA} \text{ emission})$ Exp.: I.D. Latimer and R.M. St. John, Phys. Rev. A 1, 1612 (1970).

Accuracy:

Systematic error < $\pm 10\%$. Random error < $\pm 5\%$.

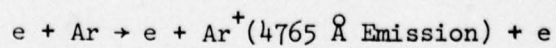
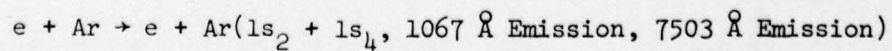
Notes:

Each reference cited includes data for a number of other excited states.



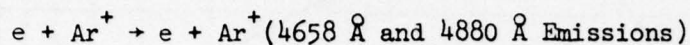
Graphical Data C-2.14.

Excitation of Argon by Electrons:



Tabular Data C-2.15.

Excitation of Argon Ions by Electrons:



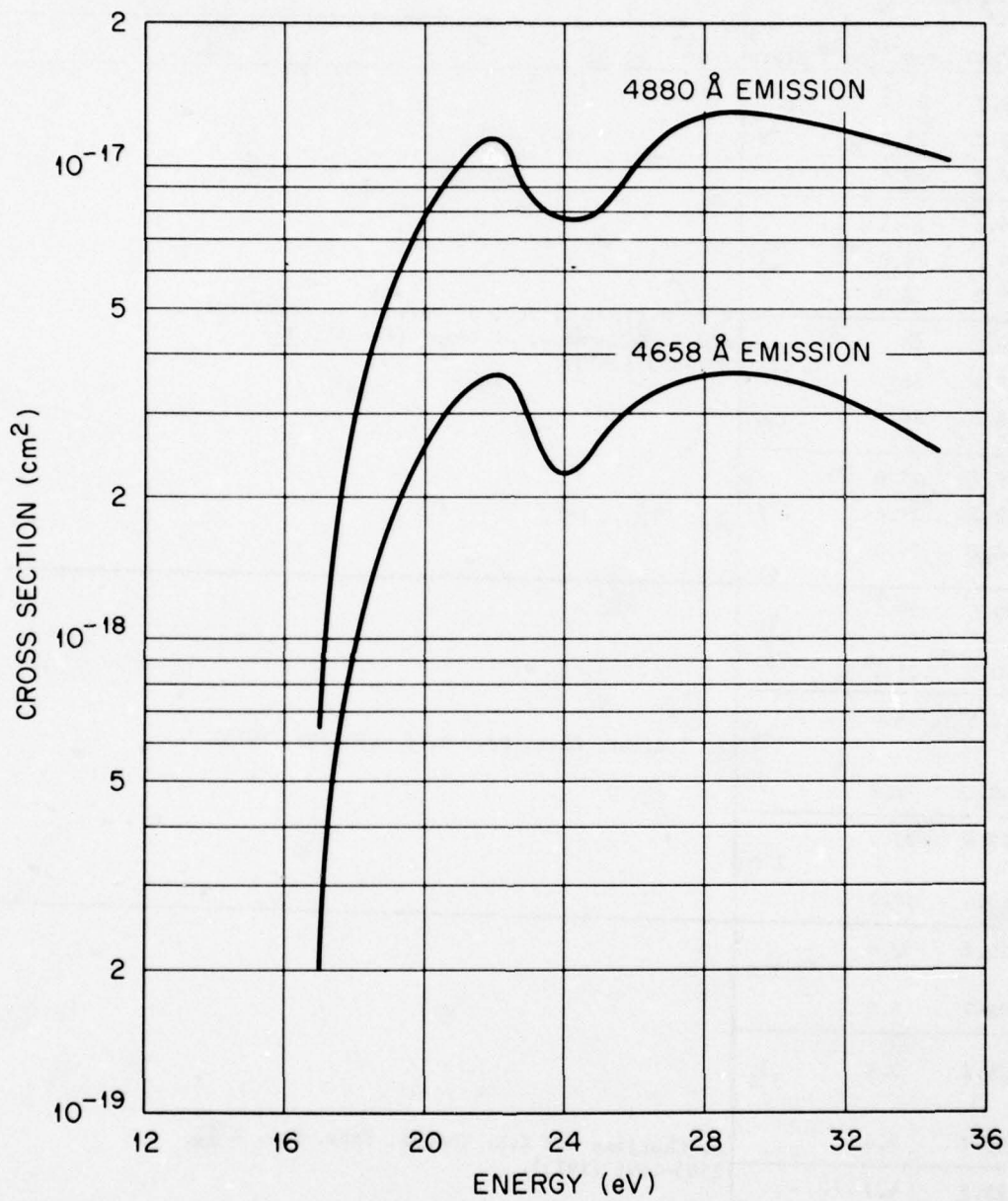
Energy (eV)	Experimental Cross Sections (cm ²)	
	4658 Å Emission ($4p^2P^{\circ} \rightarrow 4s^2P_3$) _{2 2}	4880 Å Emission ($4p^2D_3^{\circ} \rightarrow 4s^2P_3$) _{2 2}
1.7 E 01	2.00 E-19	6.50 E-19
1.8 E 01	9.60 E-19	2.89 E-18
1.9 E 01	1.75 E-18	5.30 E-18
2.0 E 01	2.54 E-18	7.80 E-18
2.1 E 01	3.25 E-18	1.00 E-17
2.2 E 01	3.60 E-18	1.13 E-17
2.3 E 01	2.81 E-18	8.67 E-18
2.4 E 01	2.24 E-18	7.79 E-18
2.5 E 01	2.64 E-18	8.10 E-18
2.6 E 01	3.21 E-18	9.80 E-18
2.7 E 01	3.41 E-18	1.18 E-17
2.8 E 01	3.58 E-18	1.28 E-17
2.9 E 01	3.62 E-18	1.30 E-17
3.0 E 01	3.58 E-18	1.27 E-17
3.1 E 01	3.41 E-18	1.23 E-17
3.2 E 01	3.20 E-18	1.19 E-17
3.3 E 01	2.95 E-18	1.13 E-17
3.4 E 01	2.68 E-18	1.08 E-17
3.5 E 01		1.02 E-17

References:

$e + \text{Ar}^+ \rightarrow e + \text{Ar}^+ (4658 \text{ and } 4880 \text{ \AA} \text{ Emission})$ Exp: A.M. Imre, A.I. Dashchenko, I.P. Zapesochnyi, and V.A. Kel'man, Zh. Eks. i Teor. Fiz. Pis. Red. 15, 712 (1972) [JETP Letters 15, 503 (1972)].

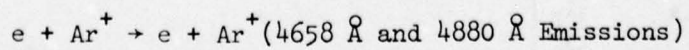
Accuracy:

Systematic error < ± 40%. Random error < ± 15%.



Graphical Data C-2.16.

Excitation of Argon Ions by Electrons:



Tabular Data C-2.17.

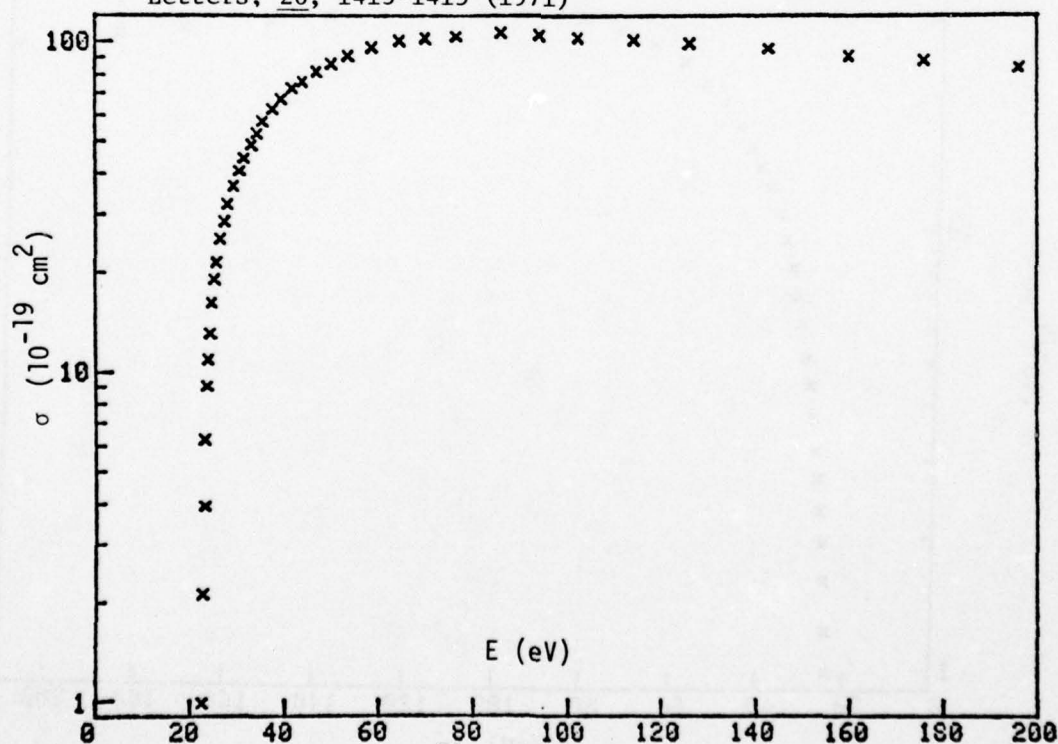
Cross sections for electron excitation of $n = 2$ and $n = 3$ states of helium

E(eV)	$\sigma(10^{-19} \text{ cm}^2)$	State	
29.2	24.1	2^1S	R.I. Hall, G. Joyez, J. Mazeau, J. Reinhardt, and C. Schermann, J. Phys. (Paris), <u>34</u> , 827-843 (1973).
39.2	21.0		
48.2	19.6		
29.2	17.1	2^3S	
39.2	14.0		
48.2	8.0		
29.2	40	2^1P	
39.2	68		
48.2	84		
29.2	27.6	2^3P	
39.2	21.4		
48.2	14.0		
29.6	29.1	2^1S	S. Trajmar, Phys. Rev. A, <u>8</u> , 191-203 (1973)
40.1	21.1		
29.6	19.4	2^3S	
40.1	12.2		
29.6	23.4	2^3P	
40.0	17.7		
29.2	3.5	3^1S	A. Chutjian and L.D. Thomas, Phys. Rev. A <u>11</u> , 1583-1595 (1975).
39.7	4.4		
29.2	3.8	3^3S	
39.7	2.4		
29.2	4.7	3^3P	
39.7	4.1		
29.2	7.6	3^1P	
39.7	15.9	3^1D	
		3^3D	

Tabular and Graphical Data C-2.18. (Provided by J. Gallagher (1977))
Electron excitation of He 2 singlet P state

$E(\text{eV})$	$\sigma(10^{-19} \text{ cm}^2)$	$E(\text{eV})$	$\sigma(10^{-19} \text{ cm}^2)$
22.40	0.99	39.42	67.48
22.58	2.12	41.78	72.73
22.96	3.91	43.91	76.45
23.15	6.23	46.93	81.72
23.54	9.04	50.16	86.63
23.74	10.85	53.61	91.07
24.14	13.03	58.74	96.55
24.54	16.17	64.37	100.70
25.16	19.09	69.95	102.40
25.58	21.44	76.64	104.10
26.45	25.31	86.10	106.80
27.34	28.67	94.35	105.10
28.03	32.20	102.50	103.40
29.22	36.48	114.20	101.70
30.46	40.64	126.20	99.26
31.49	44.53	143.00	96.06
33.10	48.79	160.00	91.43
34.22	53.02	176.00	88.48
35.38	57.62	196.10	84.21
37.50	62.61		

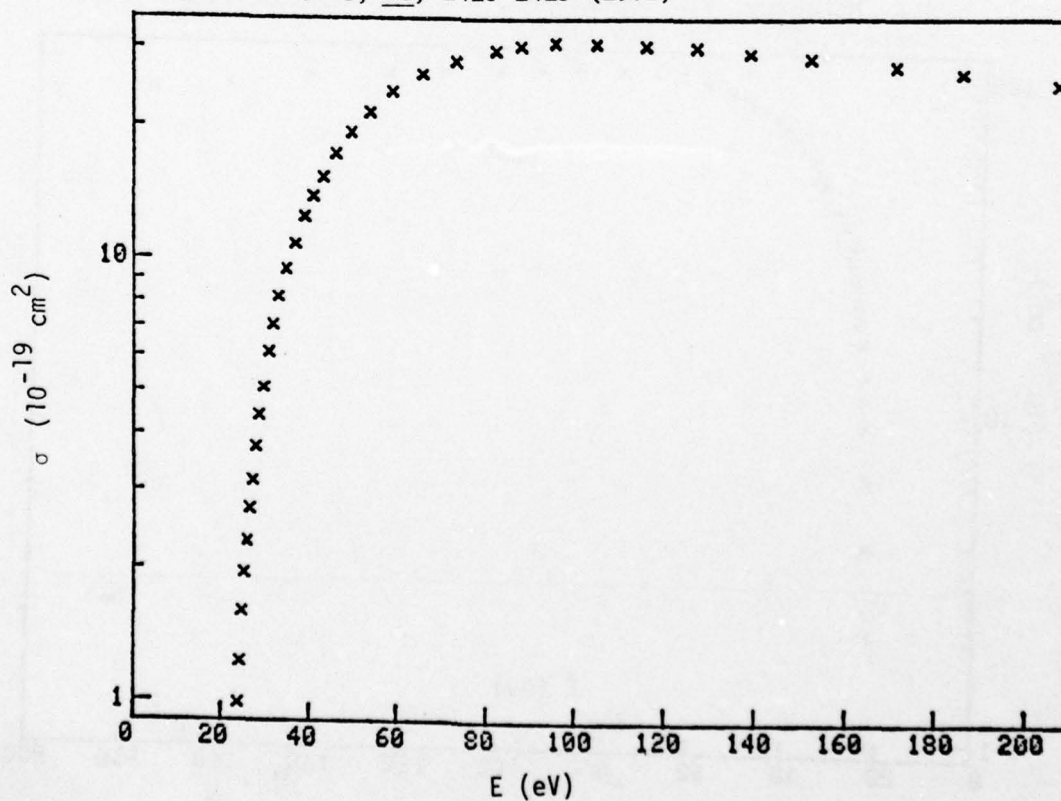
J.W. McConkey, F.G. Donaldson, and M.A. Hender, *Phys. Rev. Letters*, **26**, 1413-1415 (1971)



Tabular and Graphical Data C-2.19. (provided by J. Gallagher (1977))
Electron excitation of He 3 singlet P state

E(eV)	$\sigma(10^{-19} \text{ cm}^2)$	E(eV)	$\sigma(10^{-19} \text{ cm}^2)$
23.74	0.99	46.16	17.36
24.14	1.23	49.75	19.35
24.75	1.60	54.06	21.56
25.16	1.95	59.23	24.03
25.80	2.31	65.99	26.34
26.45	2.72	73.52	28.17
27.12	3.16	82.60	29.87
27.80	3.76	88.28	30.63
28.74	4.44	95.93	31.16
29.47	5.12	105.10	30.92
30.72	6.14	116.10	30.68
31.75	7.07	127.30	30.44
33.10	8.21	139.40	29.46
34.79	9.46	152.80	28.75
36.88	10.81	171.70	27.60
39.09	12.45	186.50	26.49
41.09	13.87	207.80	25.01
43.19	15.33		

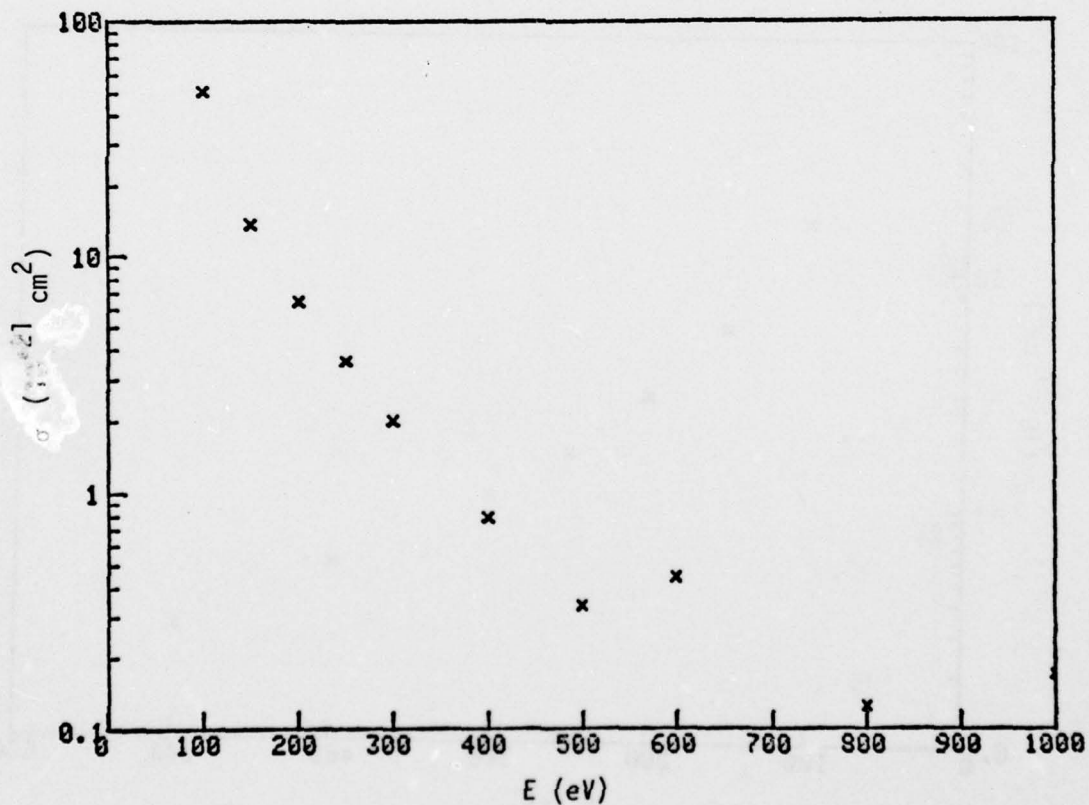
J.W. McConkey, F.G. Donaldson, and M.A. Hender, Phys.
Rev. Letters, 26, 1413-1415 (1971)



Tabular and Graphical Data C-2.20.
Electron excitation of He 3 triplet P
(Corrected for cascade from higher triplet levels)

$E(\text{eV})$	$\sigma(10^{-21} \text{ cm}^2)$
100	5.080E+001
150	1.390E+001
200	6.440E+000
250	3.610E+000
300	2.030E+000
400	7.900E-001
500	3.340E-001
600	4.400E-001
800	1.250E-001
1000	1.700E-001

A.F.J. Van Raan, P.G. Moll, and J. Van Eck,
J. Phys. B. 7, 950-965 (1974).

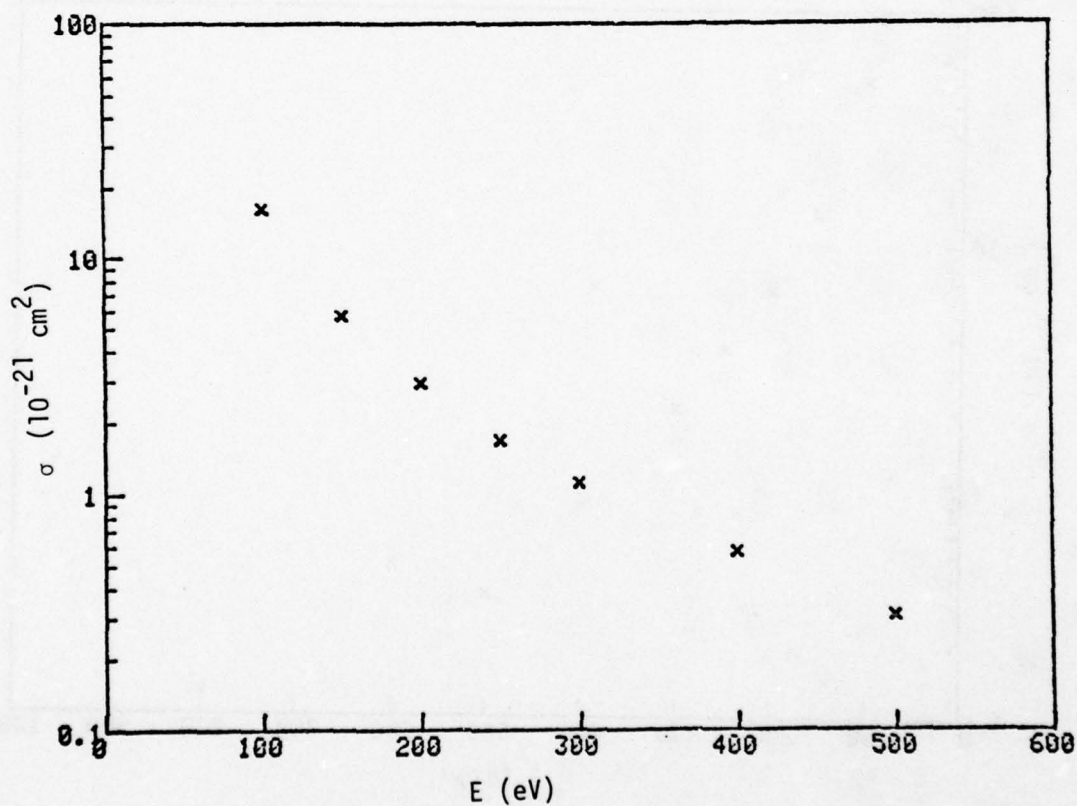


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.21.
 Electron excitation of He 4 triplet S state
 (Corrected for cascade from higher triplet levels)

$E(\text{eV})$	$\sigma(10^{-21} \text{ cm}^2)$
100	1.641E+001
150	5.720E+000
200	2.950E+000
250	1.700E+000
300	1.110E+000
400	5.670E-001
500	3.040E-001

A.F.J. Van Raan, P.G. Moll, and J. Van Eck,
 J. Phys. B. 7, 950-965 (1974).

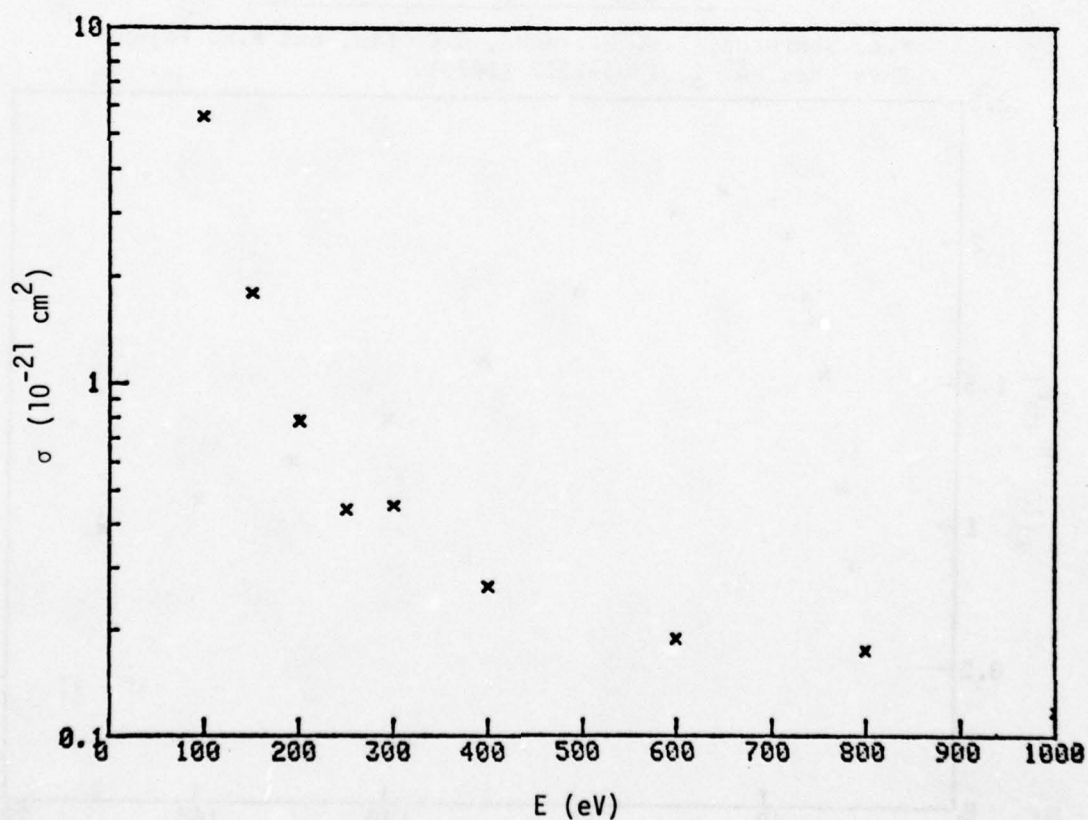


Graph and table provided by J. Gallagher (1977)

Tabular and Graphical Data C-2.22.
Electron excitation of He 4 triplet D state
(Corrected for cascade from higher triplet levels)

$E(\text{eV})$	$\sigma(10^{-21} \text{ cm}^2)$
100	5.610E+000
150	1.790E+000
200	7.800E-001
250	4.400E-001
300	4.520E-001
400	2.660E-001
600	1.890E-001
800	1.750E-001
1000	1.180E-001

A.F.J. Van Raan, P.G. Moll, and J. Van Eck,
J. Phys. B, 7, 950-965 (1974).

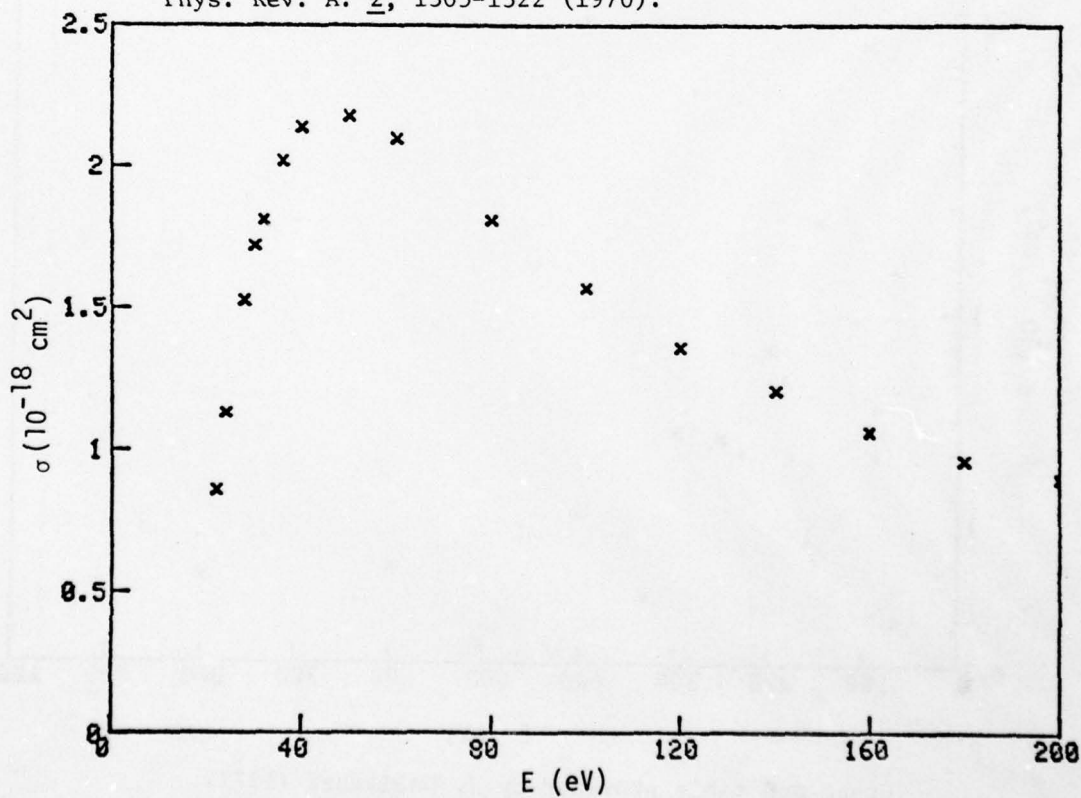


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.23.
Electron excitation of the 2p1 (J=0) level of neon

<u>E(eV)</u>	<u>$\sigma(10^{-18} \text{ cm}^2)$</u>
22	0.86
24	1.13
28	1.53
30	1.72
32	1.81
36	2.02
40	2.14
50	2.18
60	2.10
80	1.81
100	1.57
120	1.36
140	1.21
160	1.06
180	0.96
200	0.90

F.A. Sharpton, R.M. St. John, C.C. Lin, and F.E. Fajen,
Phys. Rev. A. 2, 1305-1322 (1970).

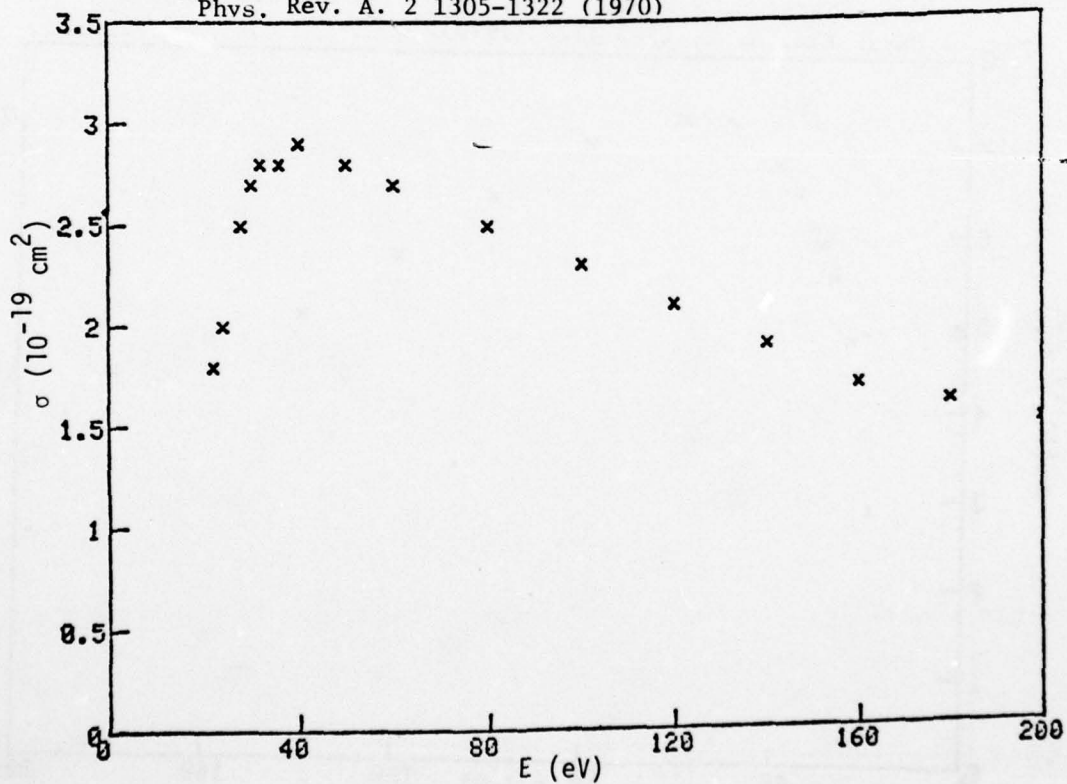


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.24.
Electron excitation of the 2p2 (J=1) level of neon
(corrected for cascade)

<u>E(eV)</u>	<u>$\sigma(10^{-19} \text{ cm}^2)$</u>
22	1.8
24	2.0
28	2.5
30	2.7
32	2.8
36	2.8
40	2.9
50	2.8
60	2.7
80	2.5
100	2.3
120	2.1
140	1.9
160	1.7
180	1.6
200	1.5

F.A. Sharpton, R.M. St. John, C.C. Lin, and F.E. Fajen,
Phys. Rev. A. 2 1305-1322 (1970)

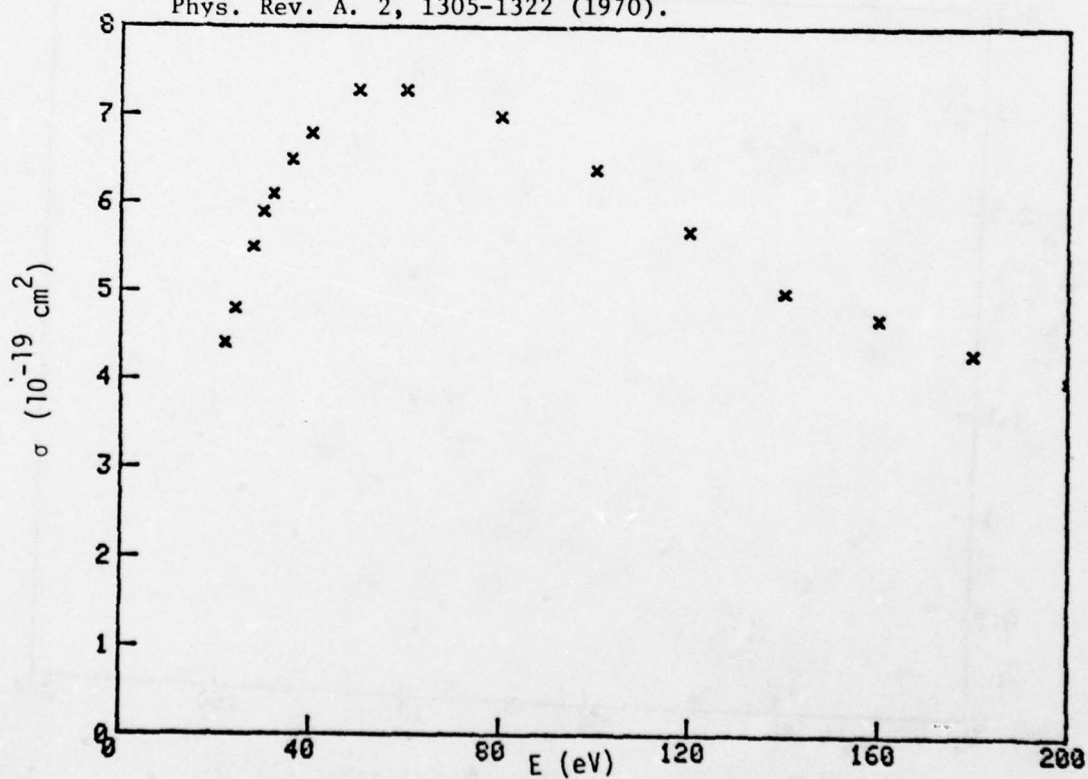


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.25.
Electron excitation of the 2p₄ (J=2) level of neon
(Corrected for cascade)

<u>E(eV)</u>	<u>$\sigma(10^{-19} \text{ cm}^2)$</u>
22	4.4
24	4.8
28	5.5
30	5.9
32	6.1
36	6.5
40	6.8
50	7.3
60	7.3
80	7.0
100	6.4
120	5.7
140	5.0
160	4.7
180	4.3
200	4.0

F.A. Sharpton, R.M. St. John, C.C. Lin, and F.E. Fajen,
Phys. Rev. A. 2, 1305-1322 (1970).

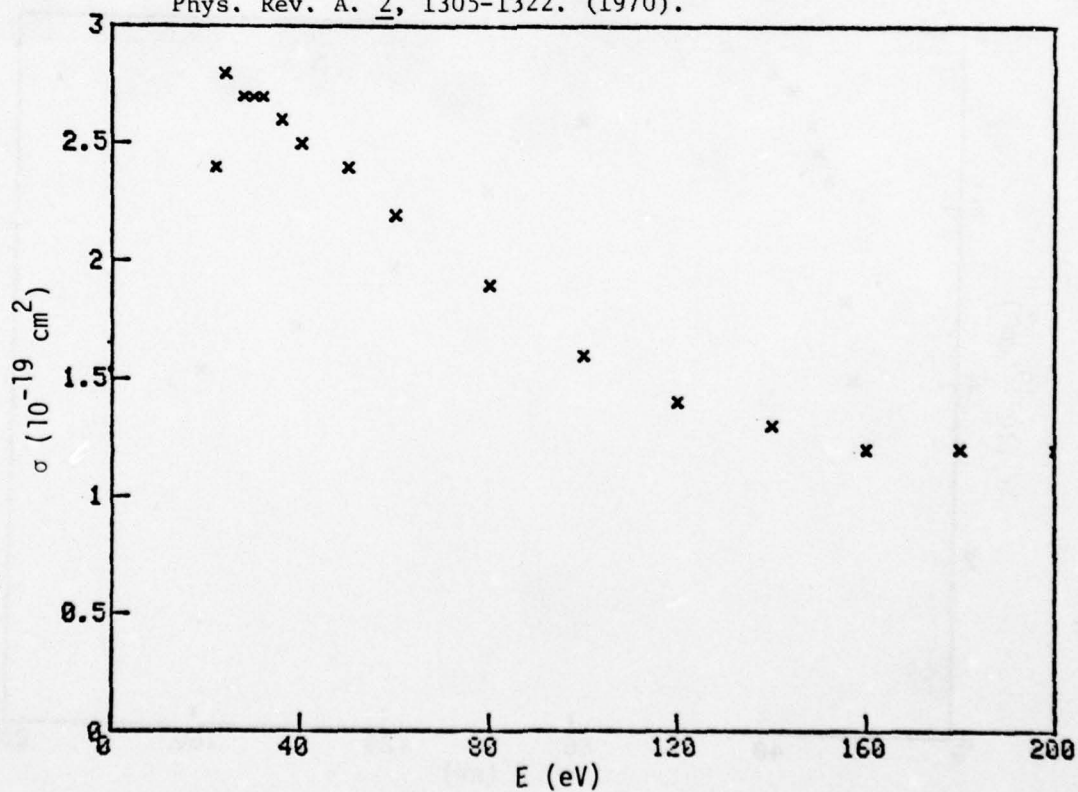


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.26.
Electron excitation of the 2p5 (J=1) level of neon
(Corrected for cascade)

<u>E(eV)</u>	<u>$\sigma(10^{-19} \text{ cm}^2)$</u>
22	2.4
24	2.8
28	2.7
30	2.7
32	2.7
36	2.6
40	2.5
50	2.4
60	2.2
80	1.9
100	1.6
120	1.4
140	1.3
160	1.2
180	1.2
200	1.2

F.A. Sharpton, R.M. St. John, C.C. Lin, and F.E. Fajen,
Phys. Rev. A. 2, 1305-1322. (1970).

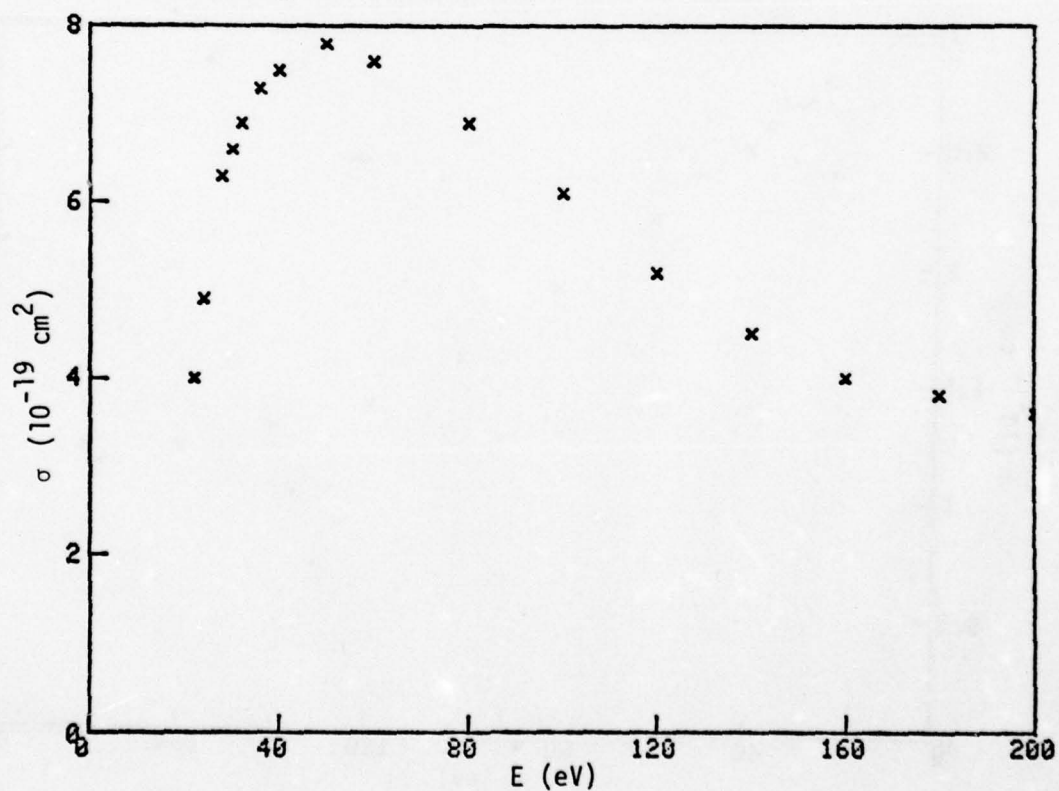


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.27.
Electron excitation of the 2p6 (J=2) level of neon
(Corrected for cascade)

$E(\text{eV})$	$\sigma(10^{-19} \text{ cm}^2)$
22	4.0
24	4.9
28	6.3
30	6.6
32	6.9
36	7.3
40	7.5
50	7.8
60	7.6
80	6.9
100	6.1
120	5.2
140	4.5
160	4.0
180	3.8
200	3.6

F.A. Sharpton, R.M. St. John, C.C. Lin and F.E. Fajen, Phys. Rev. A. 2 1305-1322 (1970)

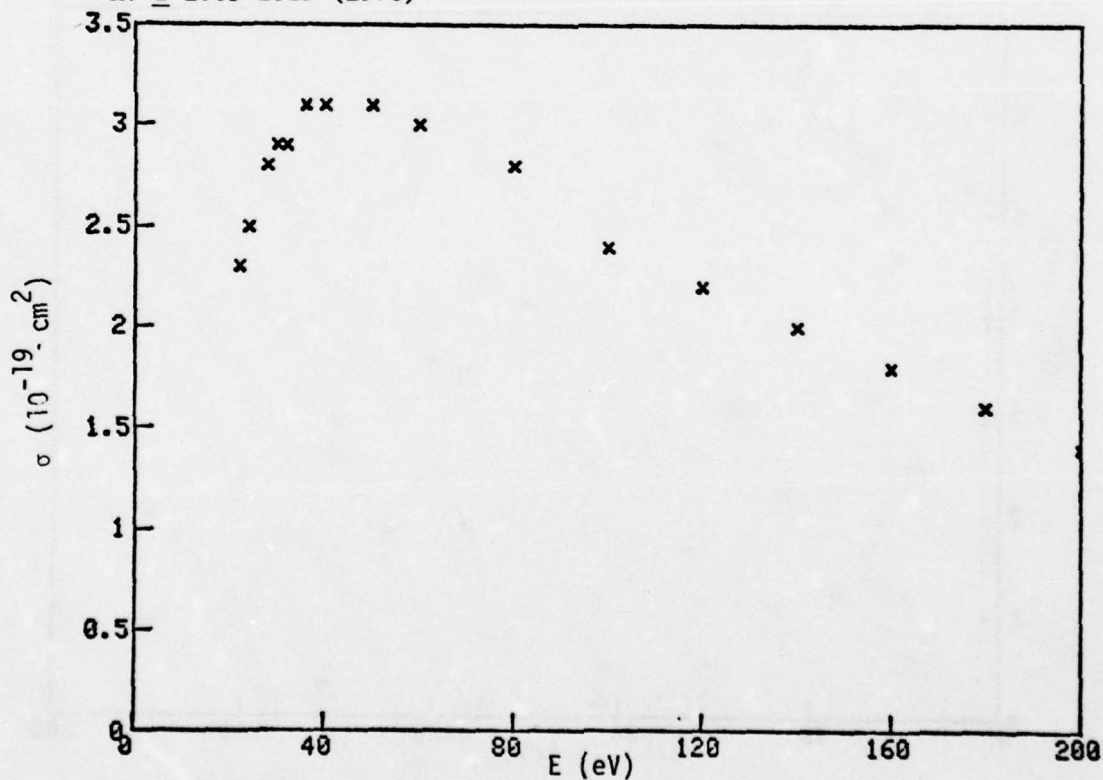


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.28.
Electron excitation of the 2p7 (J=1) state of neon
(Corrected for cascade)

E(eV)	$\sigma(10^{-19} \text{ cm}^2)$
22	2.3
24	2.5
28	2.8
30	2.9
32	2.9
36	3.1
40	3.1
50	3.1
60	3.0
80	2.8
100	2.4
120	2.2
140	2.0
160	1.8
180	1.6
200	1.4

F.A. Sharpton, R.M. St. John, C.C. Lin and F.E. Fajen, Phys. Rev.
A. 2 1305-1322 (1970)

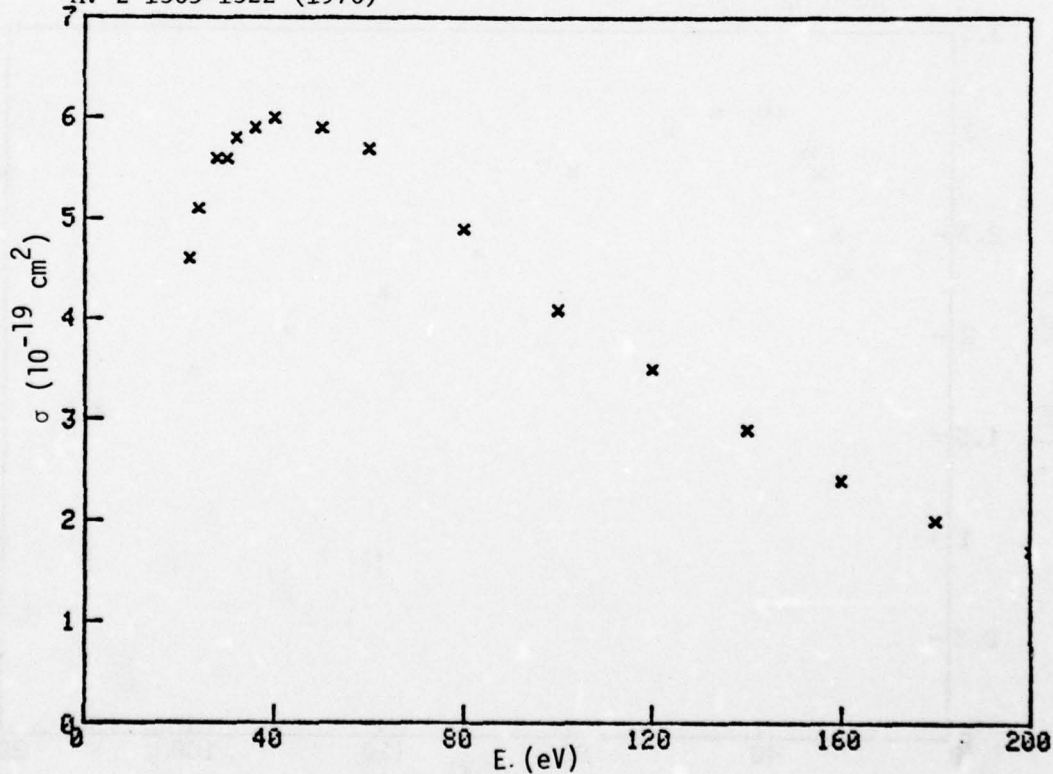


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.29.
Electron excitation of the 2p8 (J=2) state of neon
(Corrected for cascade).

$E(\text{eV})$	$\sigma(10^{-19} \text{ cm}^2)$
22	4.6
24	5.1
28	5.6
30	5.6
32	5.8
36	5.9
40	6.0
50	5.9
60	5.7
80	4.9
100	4.1
120	3.5
140	2.9
160	2.4
180	2.0
200	1.7

F.A. Sharpton, R.M. St. John, C.C. Lin, and F.E. Fajen, Phys. Rev. A. 2 1305-1322 (1970)

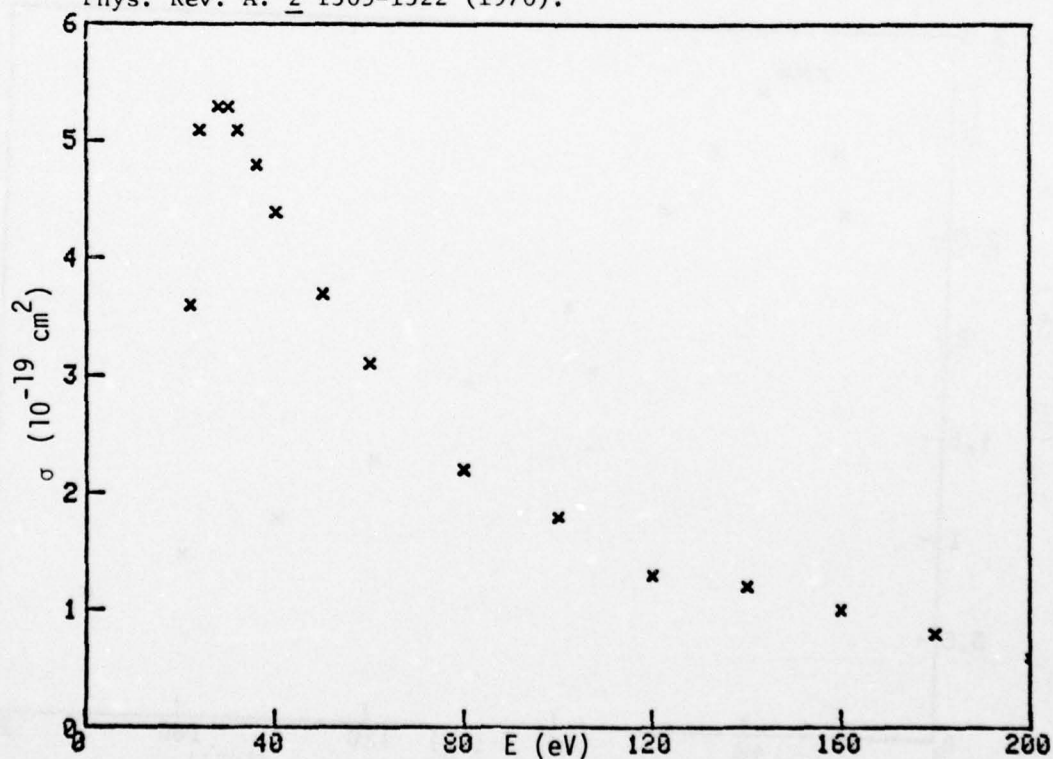


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.30.
Electron excitation of the 2p9 (J=3) level of neon
(Corrected for cascade)

<u>E(eV)</u>	<u>$\sigma(10^{-19} \text{ cm}^2)$</u>
22	3.6
24	5.1
28	5.3
30	5.3
32	5.1
36	4.8
40	4.4
50	3.7
60	3.1
80	2.2
100	1.8
120	1.3
140	1.2
160	1.0
180	0.8
200	0.6

F. A. Sharpton, R. M. St. John, C. C. Lin, and F. E. Fajen,
Phys. Rev. A. 2 1305-1322 (1970).

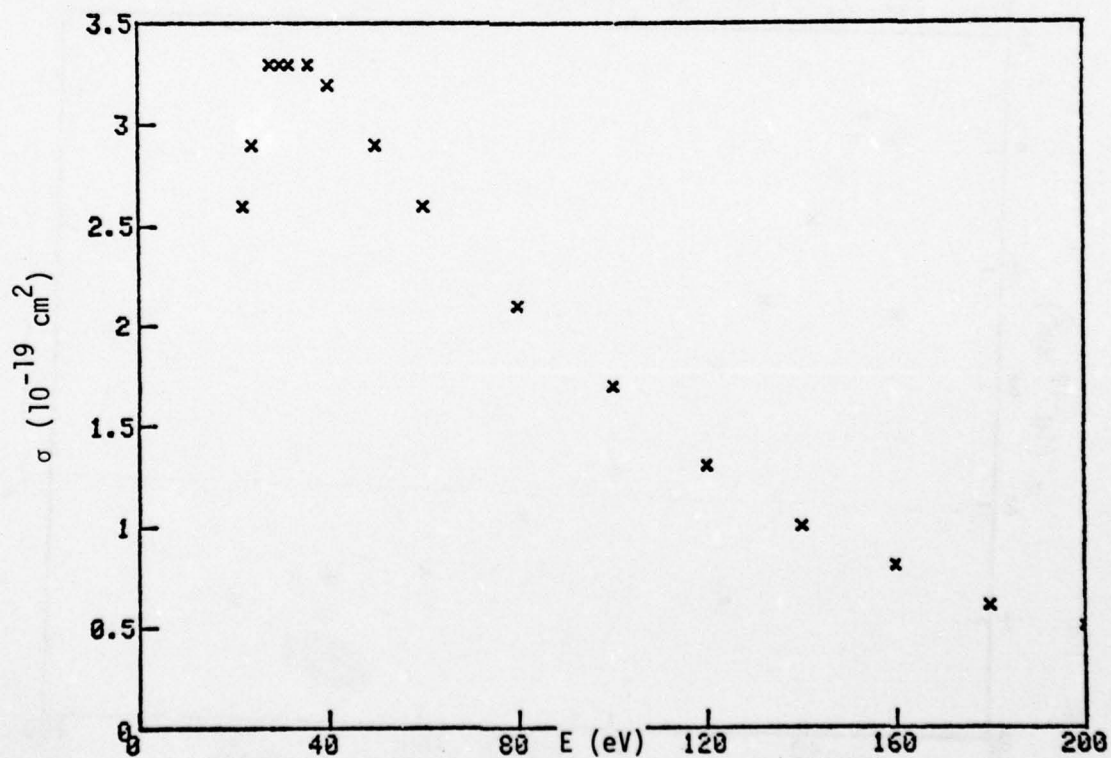


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.31.
Electron excitation of the 2p10 (J=1) level of Ne
(Corrected for cascade)

<u>E(eV)</u>	<u>$\sigma(10^{-19} \text{ cm}^2)$</u>
22	2.6
24	2.9
28	3.3
30	3.3
32	3.3
36	3.3
40	3.2
50	2.9
60	2.6
80	2.1
100	1.7
120	1.3
140	1.0
160	0.8
180	0.6
200	0.5

F.A. Sharpton, R.M. St. John, C.C. Lin, and F.E. Fajen, Phys. Rev. A. 2 1305-1322 (1970)



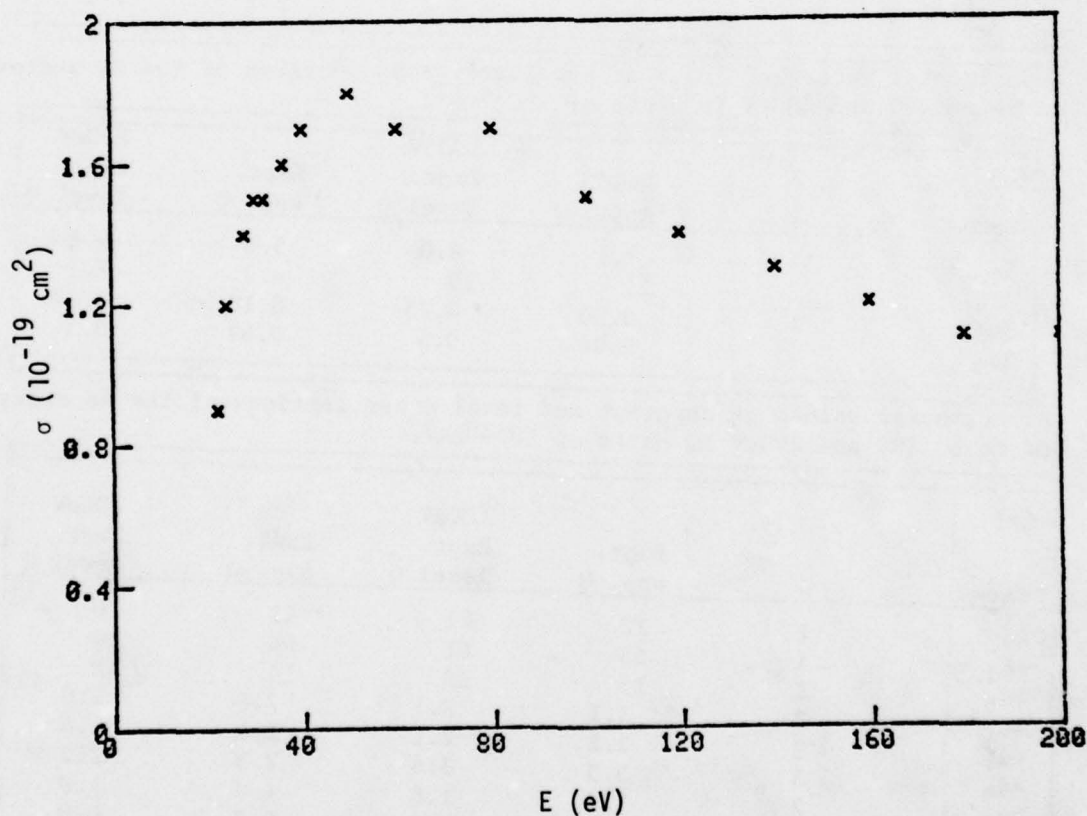
Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.32.

Cross sections for electron impact excitation of 3p and 4p levels of neon. (3p fully corrected and 4p partly corrected for cascading).

E(eV)	3p1 (J=3)	4p1	4p3	4p4	4p6	4p7	4p8
100	1×10^{-20} cm ²	2×10^{-19} cm ²	5×10^{-19} cm ²	3×10^{-20} cm ²	1×10^{-20} cm ²	1×10^{-20} cm ²	1×10^{-20} cm ²

F.A. Sharpton, R.M. St. John, C.C. Lin, and F.E. Fajen, Phys. Rev. A. 2 1305-1322. (1970)



Graph and table provided by J. Gallagher (1977).

Tabular Data C-2.33.

Experimental values of apparent and level cross sections of the 3p states of Ne at 100 and 200 eV in units of 10^{-20}cm^2 .

(a)		100eV		200eV	
States	J	Expt. app. Q	Expt. level Q	Expt. app. Q	Expt. level Q
3p ₁	0	66	64	42	41
3p ₃	0	13	10	9.1	7
3p ₄	2	7.9	5	5.6	4
3p ₆	2	8.9	4	6.0	2
3p ₈	2	12	3	8.2	1
3p ₂	1	4.6	1	3.6	1
3p ₅	1	3.3	1	1.9	...
3p ₇	1	8.2	1	6.0	...
3p ₁₀	1	5.4	1	4.3	...
3p ₉	3	4.3	1	2.2	...

Experimental values of apparent and level cross sections of the 3s states of Ne at 100 and 200eV in units of 10^{-19}cm^2 .

(b)		100eV		200eV	
States	J	Expt. appl. Q	Expt. level Q	Expt. app. Q	Expt. level Q
3s ₂	1	7.1	6.0	5.6	4.8
3s ₄	1	11	10	9.7	9.3
3s ₃	0	0.30	0.25	0.10	0.07
3s ₅	2	0.94	0.5	0.62	0.3

Experimental values of apparent and level cross sections of the 4d states of Ne at 100 and 200eV in units of 10^{-20}cm^2 .

(c)		100eV		200eV	
States	J	Expt. app. Q	Expt. level Q	Expt. app. Q	Expt. level Q
4s ₁	1	22	21	21	20
4d ₂	1	65	61	64	60
4d ₅	1	15	13	14	12
4s ₁ '	3	3.1	3.1	2.0	2.0
4d ₁	3	2.2	2.1	1.4	1.4
4d ₄	3	3.5	3.4	2.3	2.2
4s ₁ '	2	1.6	1.6	1.0	1.0
4s ₁ '	2	1.3	1.3	0.9	0.9
4d ₁ '	2	1.7	1.6	1.2	1.2
4d ₃	2	1.8	1.2	1.3	0.8
4d ₆	0	0.6	0.3	0.4	0.2
4d ₄	4	2.0	1.9	1.4	1.4

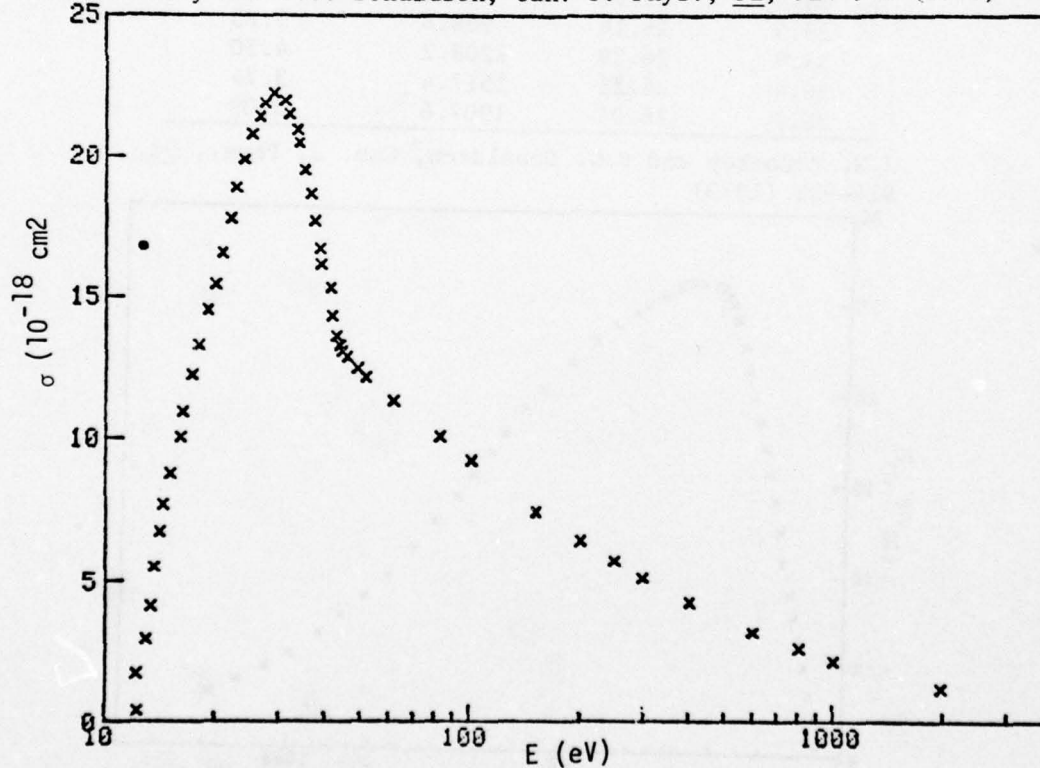
F.A. Sharpton, R.M. St. John, C.C. Lin, F.E. Fajen, Phys. Rev. A. 2 1305-1322 (1970).

Tabular and Graphical Data C-2.34.

Electron excitation of the 1067A line of Ar Polarization free measurements.

E(eV)	$\sigma(10^{-18} \text{ cm}^2)$	E(eV)	$\sigma(10^{-18} \text{ cm}^2)$	E(eV)	$\sigma(10^{-18} \text{ cm}^2)$
12.3	0.39	23.9	19.90	43.8	13.28
12.2	1.73	25.1	20.79	44.5	13.08
13.0	2.95	26.5	21.46	45.9	12.86
13.3	4.11	27.4	21.90	48.9	12.47
13.6	5.51	28.9	22.26	51.7	12.16
14.1	6.70	31.0	21.98	61.8	11.32
14.4	7.68	31.7	21.54	82.9	10.09
15.1	8.78	33.4	20.95	101.5	9.25
16.0	10.05	33.8	20.50	152.1	7.44
16.3	10.94	35.2	19.54	203.7	6.42
17.2	12.23	36.6	18.69	252.0	5.70
18.0	13.28	37.4	17.74	300.2	5.10
19.1	14.54	38.6	16.70	404.0	4.25
19.9	15.45	39.1	16.18	604.7	3.18
20.9	16.55	41.3	15.32	808.5	2.59
22.0	17.82	41.7	14.33	1001.7	2.15
22.9	18.90	42.9	13.62	1988.3	1.21

J.W. McConkey and F.G. Donaldson, Can. J. Phys., 51, 914-921 (1973)

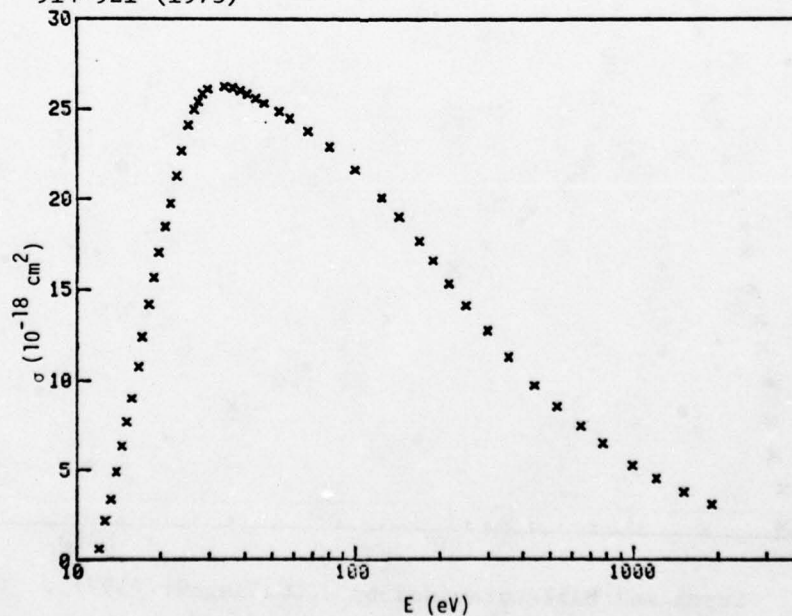


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.35. Electron excitation of the 1048A line of Ar (polarization free measurements)

$E(\text{eV})$	$\sigma(10^{-18} \text{ cm}^2)$	$E(\text{eV})$	$\sigma(10^{-18} \text{ cm}^2)$
12.0	0.60	40.9	25.87
12.6	2.17	43.9	25.63
13.2	3.35	47.0	25.37
13.8	4.88	53.2	24.90
14.5	6.36	58.1	24.53
15.1	7.68	67.4	23.83
15.7	9.00	80.7	22.92
16.6	10.76	99.8	21.68
17.1	12.39	124.4	20.09
18.1	14.16	143.1	19.00
18.9	15.67	169.6	17.65
19.6	17.04	189.8	16.59
20.6	18.50	218.1	15.33
21.6	19.78	251.1	14.10
22.8	21.34	298.8	12.73
23.8	22.70	356.7	11.29
25.1	24.15	440.9	9.73
26.4	25.02	531.6	8.54
27.3	25.44	646.0	7.46
28.3	25.87	776.2	6.47
29.5	26.14	988.8	5.23
33.9	26.29	1208.2	4.50
36.4	26.21	1517.4	3.74
38.7	26.04	1907.6	3.09

J.W. McConkey and F.G. Donaldson, Can. J. Phys., 51, 914-921 (1973)

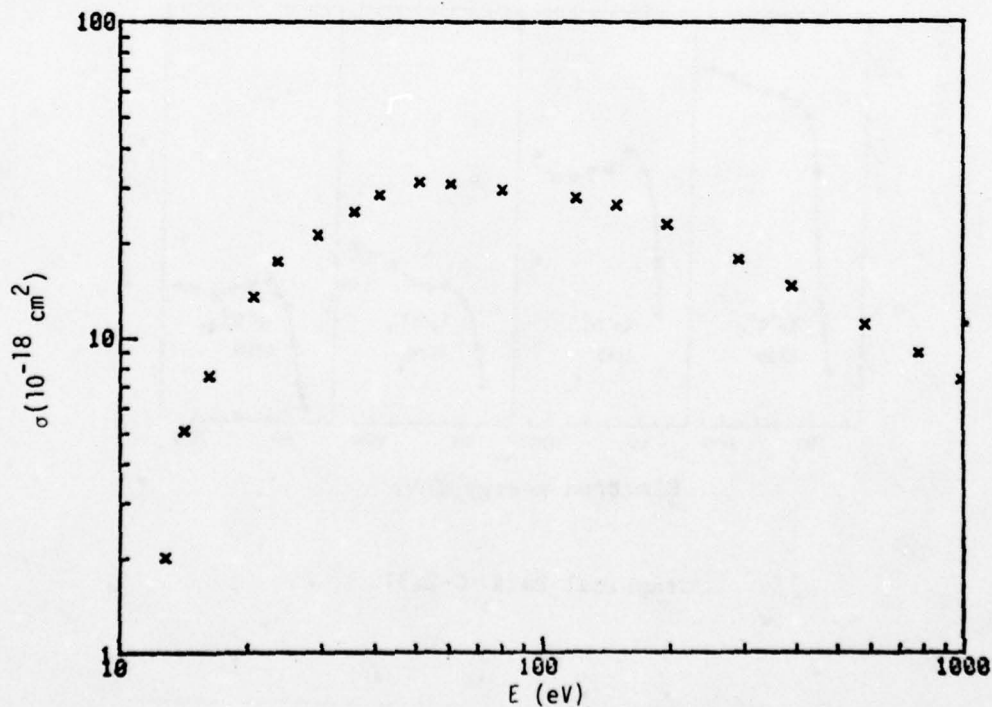


Graph and table provided by J. Gallagher (1977).

Tabular and Graphical Data C-2.36.
Electron excitation of Ar combined 4s(4s') states (cascade corrected)
(Normalized to the Born data at high energy).

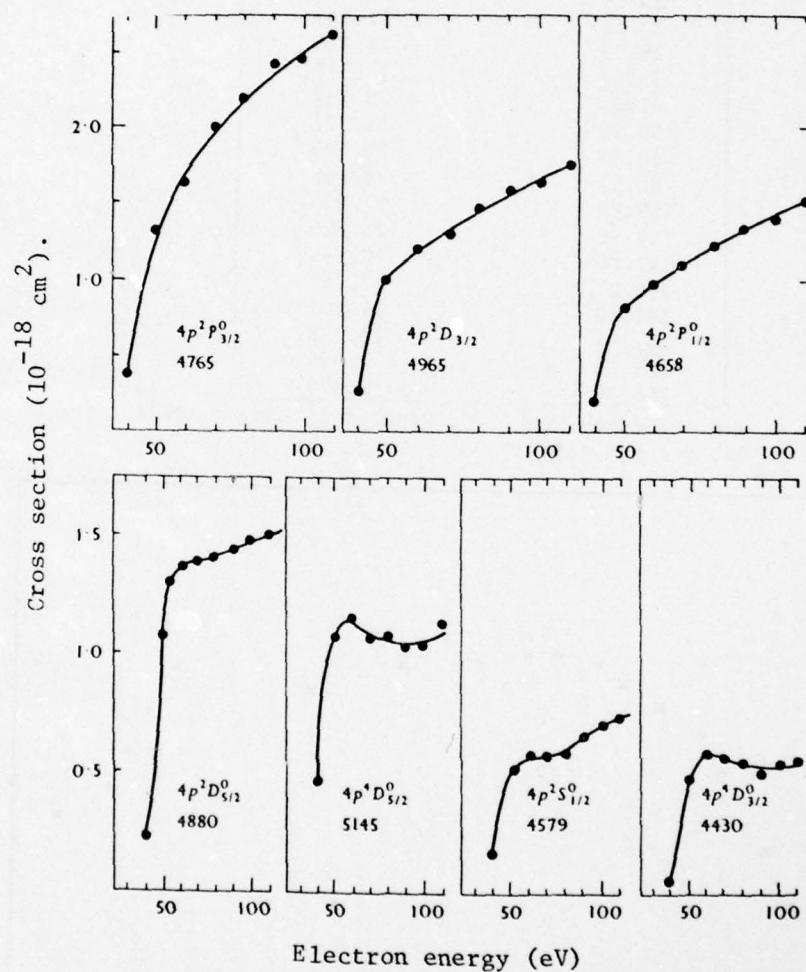
E(eV)	$\sigma(10^{-18} \text{ cm}^2)$
12.80	2.020
14.18	5.091
16.20	7.608
20.64	13.521
23.51	17.503
29.33	21.320
35.67	25.315
41.03	28.707
50.96	31.377
60.55	30.899
80.27	29.768
119.97	27.954
149.98	26.520
197.76	22.878
294.27	17.755
392.80	14.621
583.94	11.038
782.14	8.974
986.39	7.375

J.W. McConkey and F.G. Donaldson, Can. J. Phys.,
51, 914-921 (1973)



Graph and table provided by J. Gallagher (1977).

Apparent cross-sections for simultaneous ionization and excitation of argon, measured by Bennett, et al. The cross sections for the excited states of Ar^+ specified were obtained from intensity measurements of the lines of the Ar II spectrum whose wavelengths (in Å) are given on the curves. See the book by Massey and Burhop, Vol. 1, p. 230.



Graphical Data C-2.37.

Tabular Data C-2.38.

Cross sections for the production of fluorescence in xenon.

		9163 Å			
Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
9.700+000	6.700-020	1.670+001	1.007-017	4.420+001	5.490-018
1.010+001	5.700-019	1.770+001	9.750-018	4.620+001	5.320-018
1.060+001	2.160-018	1.880+001	9.320-018	4.900+001	6.450-018
1.110+001	3.830-018	2.040+001	8.680-018	5.200+001	6.490-018
1.160+001	4.850-018	2.300+001	7.800-018	6.030+001	6.500-018
1.230+001	6.500-018	2.480+001	7.230-018	6.530+001	6.520-018
1.290+001	8.200-018	2.570+001	6.370-018	7.000+001	6.400-018
1.330+001	9.100-018	3.110+001	6.080-018	7.530+001	6.440-018
1.370+001	9.710-018	3.360+001	6.130-018	8.020+001	6.380-018
1.400+001	9.990-018	3.650+001	6.320-018	8.980+001	6.280-018
1.440+001	1.016-017	3.900+001	6.280-018	9.980+001	6.090-018
1.560+001	1.027-017	4.150+001	6.360-018		
		9513 Å			
Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
1.190+001	4.590-019	1.700+001	2.968-018	3.900+001	7.120-019
1.300+001	1.682-018	1.810+001	2.662-018	4.890+001	6.010-019
1.440+001	2.557-018	1.910+001	2.193-018	5.890+001	5.430-019
1.500+001	2.799-018	2.110+001	1.708-018	6.860+001	4.530-019
1.550+001	3.063-018	2.420+001	1.228-018	7.840+001	4.220-019
1.630+001	3.063-018	2.960+001	8.700-019	8.830+001	3.850-019
				9.830+001	3.580-019
		9800 Å			
Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
1.030+001	1.240-018	1.440+001	1.877-017	4.290+001	4.640-018
1.080+001	2.330-018	1.540+001	1.723-017	4.820+001	4.570-018
1.130+001	3.250-018	1.620+001	1.691-017	5.280+001	4.350-018
1.140+001	5.390-018	1.770+001	1.244-017	5.770+001	4.050-018
1.190+001	9.540-018	2.100+001	8.020-018	6.760+001	4.170-018
1.260+001	1.433-017	2.380+001	6.510-018	7.770+001	4.170-018
1.290+001	1.684-017	2.820+001	5.560-018	8.690+001	4.320-018
1.320+001	1.877-017	3.320+001	5.260-018	9.710+001	4.020-018
1.370+001	1.910-017	3.830+001	4.940-018		
		9923 Å			
Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
1.030+001	1.610-018	1.740+001	1.653-017	3.980+001	8.820-018
1.130+001	3.520-018	1.870+001	1.552-017	4.480+001	9.160-018
1.140+001	5.880-018	2.020+001	1.417-017	4.990+001	9.100-018
1.230+001	9.200-018	2.250+001	1.242-017	5.450+001	8.920-018
1.350+001	1.330-017	2.510+001	1.053-017	5.970+001	8.860-018
1.400+001	1.603-017	2.780+001	9.290-018	6.940+001	8.900-018
1.420+001	1.721-017	3.270+001	9.310-018	7.940+001	8.650-018
1.480+001	1.790-017	3.490+001	9.280-018	8.840+001	8.840-018
1.640+001	1.745-017	3.750+001	9.120-018	9.850+001	8.670-018

Feynman, P. V., Zapesochny, I. P., Ukr. Fiz. Zh., 13, 205 (1968)

Table from Kieffer Laser Data Report (1973).

Tabular Data C-2.39.
Cross sections for the production of fluorescence in xenon.

8347 Å					
Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
1.160+001	6.730-019	1.890+001	3.237-018	3.390+001	1.983-018
1.250+001	1.870-018	1.990+001	3.167-018	4.490+001	1.940-018
1.380+001	2.483-018	2.080+001	3.060-018	4.980+001	1.873-018
1.480+001	2.833-018	2.190+001	2.933-018	5.960+001	1.687-018
1.510+001	3.117-018	2.330+001	2.693-018	6.930+001	1.643-018
1.610+001	3.170-018	2.740+001	2.413-018	7.920+001	1.593-018
1.660+001	3.137-018	2.990+001	2.303-018	8.950+001	1.547-018
1.710+001	3.233-018	3.210+001	2.193-018	9.900+001	1.530-018
1.800+001	3.213-018	3.490+001	2.077-018		
8819 Å					
Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
1.000+001	1.950-018	1.570+001	2.092-017	3.510+001	5.670-018
1.090+001	5.540-018	1.750+001	1.834-017	4.000+001	5.300-018
1.120+001	9.020-018	1.860+001	1.631-017	4.500+001	4.850-018
1.170+001	1.359-017	2.040+001	1.256-017	4.990+001	4.670-018
1.260+001	1.876-017	2.250+001	9.660-018	5.980+001	4.620-018
1.290+001	2.082-017	2.510+001	8.180-018	6.990+001	4.300-018
1.330+001	2.166-017	2.740+001	6.830-018	7.960+001	4.208-018
1.430+001	2.253-017	3.030+001	6.360-018	8.910+001	3.960-018
1.480+001	2.219-017	3.280+001	5.620-018	9.940+001	4.048-018
8952 Å					
Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
1.000+001	2.050-019	1.570+001	3.715-018	3.500+001	1.901-018
1.040+001	1.000-018	1.680+001	3.642-018	4.010+001	1.755-018
1.100+001	1.404-018	1.760+001	3.457-018	4.530+001	1.755-018
1.140+001	2.025-018	1.880+001	3.193-018	5.000+001	1.729-018
1.200+001	2.689-018	2.000+001	3.126-018	6.020+001	1.556-018
1.290+001	3.470-018	2.240+001	2.881-018	7.020+001	1.596-018
1.320+001	3.623-018	2.490+001	2.517-018	7.990+001	1.490-018
1.390+001	3.722-018	2.780+001	2.424-018	9.030+001	1.550-018
1.470+001	3.801-018	3.020+001	2.132-018	1.005+002	1.497-018
9045 Å					
Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
1.040+001	9.150-019	1.830+001	5.931-018	3.410+001	3.757-018
1.140+001	2.833-018	1.910+001	5.548-018	3.700+001	3.748-018
1.210+001	4.505-018	2.010+001	5.449-018	4.410+001	3.679-018
1.320+001	5.351-018	2.210+001	4.859-018	4.900+001	3.689-018
1.400+001	5.626-018	2.420+001	4.415-018	5.410+001	3.600-018
1.470+001	5.862-018	2.650+001	3.826-018	5.970+001	3.767-018
1.620+001	6.108-018	2.980+001	3.846-018	6.870+001	3.659-018
1.680+001	5.980-018	3.190+001	3.855-018	7.840+001	3.649-018
				9.890+001	3.608-018

Feltsan, P. V., Zapesochny, I. P., Ukr. Fiz. Zh., 13, 205 (1968)

Table from Kieffer Laser Data Report (1973).

Tabular Data C-2.40.
Cross sections for the production of fluorescence in xenon.

Energy (eV)	Cross Section (cm ²)	Energy (eV)	⁷⁸⁸⁷ Å Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
1.180+001	3.490-019	2.260+001	2.125-018	3.440+001	2.312-018
1.250+001	8.020-019	2.360+001	2.302-018	3.670+001	2.208-018
1.350+001	9.580-019	2.440+001	2.455-018	3.940+001	2.062-018
1.430+001	9.940-019	2.540+001	2.558-018	4.420+001	1.892-018
1.560+001	1.021-018	2.660+001	2.624-018	4.920+001	1.776-018
1.700+001	1.081-018	2.760+001	2.644-018	5.460+001	1.660-018
1.810+001	1.247-018	2.860+001	2.621-018	5.960+001	1.537-018
1.890+001	1.407-018	2.940+001	2.581-018	6.930+001	1.443-018
2.010+001	1.653-018	3.060+001	2.508-018	7.320+001	1.354-018
2.110+001	1.892-018	3.190+001	2.455-018	8.900+001	1.287-018
				9.920+001	1.261-018

Energy (eV)	Cross Section (cm ²)	Energy (eV)	⁷⁹⁶⁷ Å Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
1.190+001	1.268-019	2.160+001	8.688-019	4.930+001	4.150-019
1.360+001	7.180-019	2.360+001	6.940-019	5.880+001	4.210-019
1.470+001	1.082-018	2.630+001	6.000-019	6.870+001	3.640-019
1.560+001	1.162-018	2.980+001	5.300-019	7.870+001	3.750-019
1.660+001	1.183-018	3.390+001	4.290-019	8.870+001	3.788-019
1.740+001	1.160-018	3.940+001	4.100-019	9.900+001	3.640-019
1.950+001	1.018-018	4.420+001	4.120-019		

8231A

Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
1.040+001	1.538-018	1.840+001	5.250-018	4.530+001	2.844-018
1.120+001	3.249-018	2.010+001	4.762-018	4.990+001	2.712-018
1.250+001	4.787-018	2.230+001	4.043-018	5.500+001	2.637-018
1.310+001	5.564-018	2.490+001	3.571-018	6.030+001	2.629-018
1.350+001	5.828-018	2.740+001	3.290-018	6.500+001	2.546-018
1.400+001	5.085-018	3.020+001	3.166-018	7.010+001	2.555-018
1.550+001	5.911-018	3.260+001	3.150-018	8.000+001	2.555-018
1.650+001	5.754-018	3.510+001	3.018-018	8.980+001	2.505-018
1.760+001	5.489-018	4.030+001	2.927-018	1.005+002	2.521-018

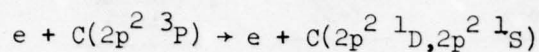
8280A

Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)	Energy (eV)	Cross Section (cm ²)
9.600+000	1.490-018	1.870+001	5.781-018	3.280+001	7.381-018
1.020+001	3.050-018	1.970+001	6.193-018	3.460+001	6.646-018
1.040+001	3.993-018	2.060+001	5.646-018	3.650+001	6.525-018
1.140+001	4.520-018	2.160+001	7.073-018	3.970+001	6.189-018
1.240+001	4.520-018	2.360+001	7.663-018	4.480+001	5.901-018
1.330+001	4.172-018	2.510+001	7.937-018	4.970+001	5.662-018
1.410+001	4.192-018	2.660+001	8.075-018	5.950+001	5.513-018
1.570+001	4.579-018	2.840+001	7.967-018	6.320+001	5.374-018
1.690+001	4.868-018	3.040+001	7.848-018	7.890+001	5.095-018
1.800+001	5.354-018	3.060+001	7.518-018	8.910+001	4.987-018
				9.860+001	4.868-018

Feltsan, P. V., Zapesochny, I. P., Ukr. Fiz. Zh., 13, 205 (1968)
Table from Kieffer Laser Data Report (1973).

Tabular Data C-2.41.

Excitation of Carbon by Electrons:



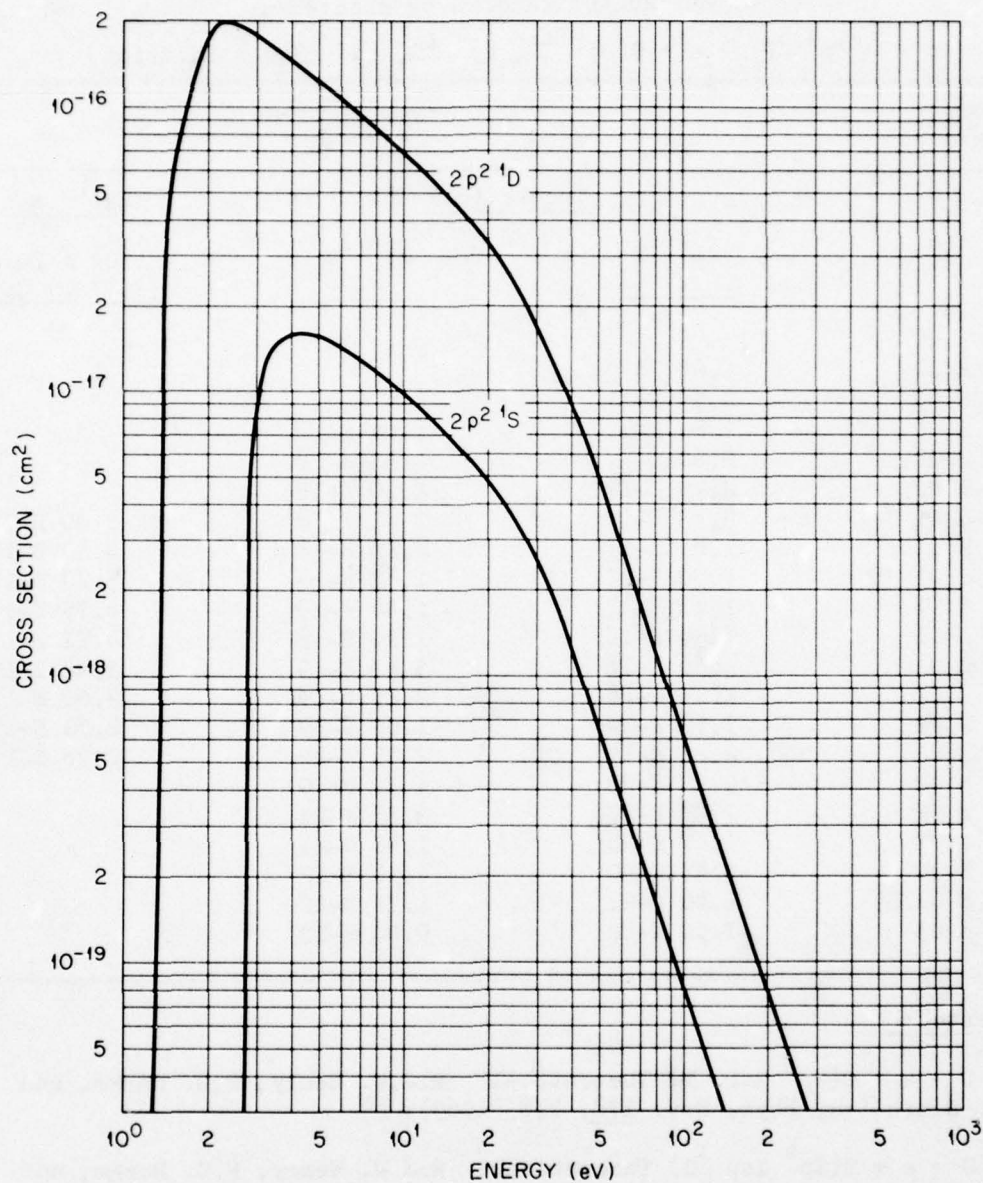
Energy (eV)	Theoretical Cross Sections (cm ²)	
	<u>2p² ¹D</u>	<u>2p² ¹S</u>
1.0 E 00		
2.0 E 00	1.70 E-16	
3.0 E 00	1.75 E-16	8.00 E-18
4.0 E 00	1.46 E-16	1.58 E-17
6.0 E 00	1.06 E-16	1.42 E-17
8.0 E 00	8.40 E-17	1.18 E-17
1.0 E 01	7.00 E-17	1.00 E-17
2.0 E 01	3.38 E-17	4.90 E-18
3.0 E 01	1.70 E-17	2.55 E-18
4.0 E 01	9.20 E-18	1.25 E-18
6.0 E 01	2.75 E-18	3.39 E-19
8.0 E 01	1.16 E-18	1.43 E-19
1.0 E 02	6.00 E-19	7.32 E-20
2.0 E 02	7.40 E-20	9.15 E-21
4.0 E 02	9.29 E-21	1.14 E-21
6.0 E 02	2.75 E-21	3.39 E-22
8.0 E 02	1.16 E-21	1.43 E-22
1.0 E 03	5.95 E-22	7.33 E-23

References:

$e + C \rightarrow e + C(2p^2 \ ^1D, 2p^2 \ ^1S)$ Theoretical: R.J.W. Henry, P.G. Burke, and A.L. Sinfailam, Phys. Rev. 178, 218 (1969).

Accuracy:

These data are theoretical cross sections. There has been no test of the theory's validity at all; the data are likely to be very inaccurate at energies close to threshold.

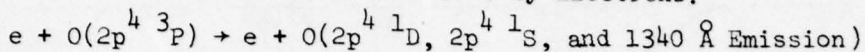


Excitation of Carbon by Electrons:
 $e + C(2p^2 \ ^3P) \rightarrow e + C(2p^2 \ ^1D, 2p^2 \ ^1S)$

Graphical Data C-2.42.

Tabular Data C-2.43.

Excitation of O by Electrons:



Energy (eV)	Cross Sections (cm ²)		
	Theoretical		Experimental
	<u>2p⁴ ¹D</u>	<u>2p⁴ ¹S</u>	<u>1304 \AA Emission</u> <u>[3s ³S → 2p⁴ ³P]</u>
2.0 E 00			
3.0 E 00	1.57 E-17		
4.0 E 00	2.55 E-17		
5.0 E 00	2.80 E-17	1.00 E-18	
6.0 E 00	2.80 E-17	1.50 E-18	
8.0 E 00	2.75 E-17	2.20 E-18	
1.0 E 01	2.33 E-17	2.42 E-18	5.80 E-18
1.5 E 01	1.85 E-17	2.08 E-18	4.50 E-17
2.0 E 01	1.50 E-17	1.87 E-18	5.20 E-17
3.0 E 01	1.10 E-17	1.44 E-18	4.75 E-17
4.0 E 01	7.50 E-18	1.10 E-18	4.21 E-17
6.0 E 01	3.50 E-18	5.40 E-19	3.44 E-17
8.0 E 01	1.63 E-18	2.15 E-19	3.00 E-17
1.0 E 02	7.50 E-19	1.00 E-19	2.70 E-17
1.5 E 02	2.25 E-19	2.75 E-20	2.28 E-17
2.0 E 02	9.70 E-20	1.12 E-20	
3.0 E 02	2.77 E-20	3.33 E-21	
4.0 E 02	1.17 E-20	1.40 E-21	
6.0 E 02	3.47 E-20	4.16 E-22	
8.0 E 02	1.46 E-21	1.75 E-22	
1.0 E 03	7.50 E-22	9.00 E-23	

References:

$e + O \rightarrow e + O(2p^4 \ ^1S \ ^1D)$ Theoretical: R.J.W. Henry, P.G. Burke, and A.L. Sinfailam, Phys. Rev. 178, 218 (1969).

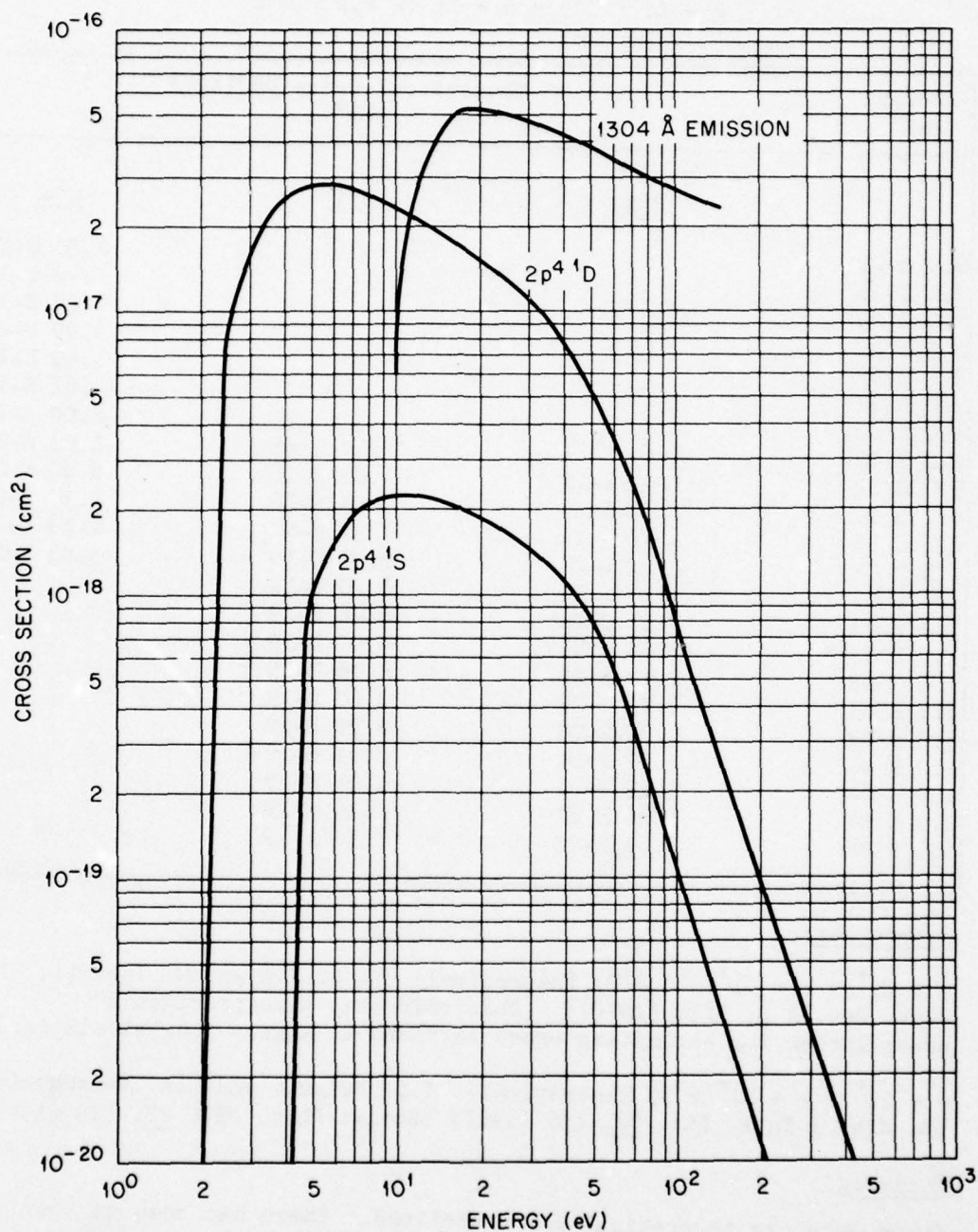
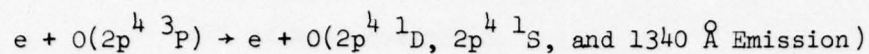
$e + O \rightarrow e + O(2p^4 \ ^1S \ ^1S)$ Theoretical: R.J.W. Henry, P.G. Burke, and A.L. Sinfailam, Phys. Rev. 178, 218 (1969).

$e + O \rightarrow e + O(1304 \text{ \AA emission})$ Exp.: E.C. Zipf - as quoted by T. Sawada and P.S. Ganas, Phys. Rev. A 7, 617 (1973).

Notes:

These data are theoretical cross sections. There has been no test of the theory's validity at all; the data are likely to be very inaccurate at energies close to threshold.

Excitation of O by Electrons:

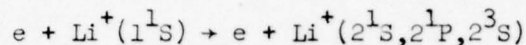


A useful set of cross sections for excitation of O is given by P.A. Kazaks et al., Phys. Rev. A 6, 2169 (1972). Though not of as high accuracy as the data we quote here, they can be of great practical utility.

Graphical Data C-2.44.

Tabular Data C-2.45.

Excitation of Lithium Ions by Electrons:



Energy (eV)	Theoretical Cross Sections (cm ²)		
	<u>2¹S</u>	<u>2¹P</u>	<u>2³S</u>
6.0 E 01			2.30 E-17
8.0 E 01			1.40 E-17
1.0 E 02			8.20 E-18
1.5 E 02			2.99 E-18
2.0 E 02			1.40 E-18
3.0 E 02			4.61 E-19
4.0 E 02			2.00 E-19
5.0 E 02	2.14 E-19	1.99 E-18	1.01 E-19
6.0 E 02	1.79 E-19	1.81 E-18	5.80 E-20
8.0 E 02	1.34 E-19	1.55 E-18	2.30 E-20
1.0 E 03	1.07 E-19	1.32 E-18	1.13 E-20
1.5 E 03	7.15 E-20	9.92 E-19	3.05 E-21
2.0 E 03	5.36 E-20	8.10 E-19	
3.0 E 03	3.57 E-20	6.06 E-19	
4.0 E 03	2.68 E-20	4.90 E-19	
5.0 E 03	2.14 E-20	4.16 E-19	
6.0 E 03	1.79 E-20	3.60 E-19	
8.0 E 03	1.34 E-20	2.87 E-19	
1.0 E 04	1.07 E-20	2.41 E-19	
1.5 E 04	7.15 E-21	1.74 E-19	
2.0 E 04	5.36 E-21	1.38 E-19	
3.0 E 04	3.57 E-21	1.00 E-19	

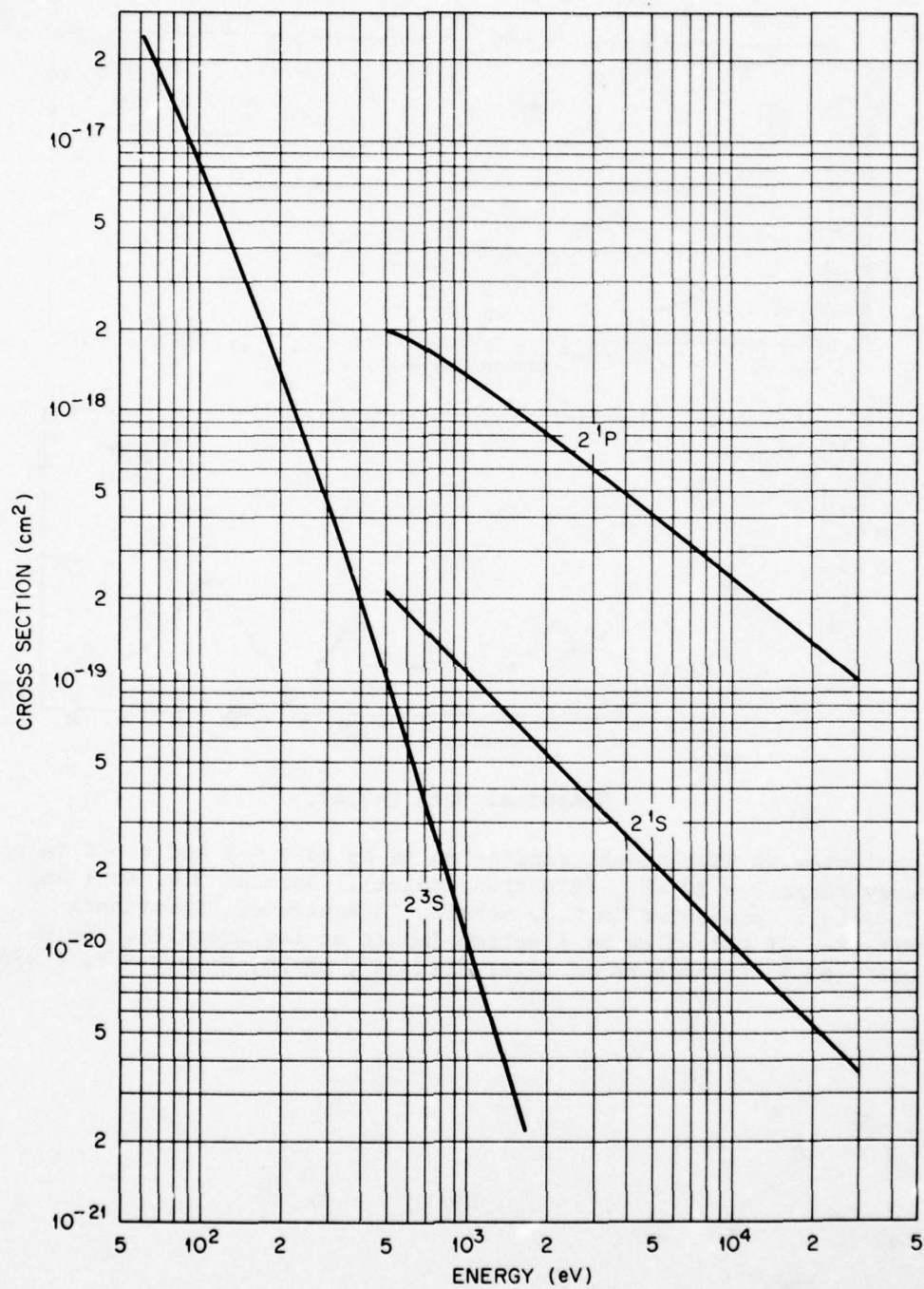
References:

$e + \text{Li}^+ \rightarrow e + \text{Li}^+(2^1\text{S}, 2^1\text{P})$ Theoretical: Y.-K. Kim and M. Inokuti, Phys. Rev. A 1, 1132 (1970). [This reference also provides a prescription for estimating cross sections to higher singlet states.]

$e + \text{Li}^+ \rightarrow e + \text{Li}^+(2^3\text{S})$ Theoretical: I.L. Beigman and L.A. Vainshtein, Zh. Eks. i Teor. Fiz. 52, 185 (1967) [Soviet Phys. JETP 25, 119 (1967)].

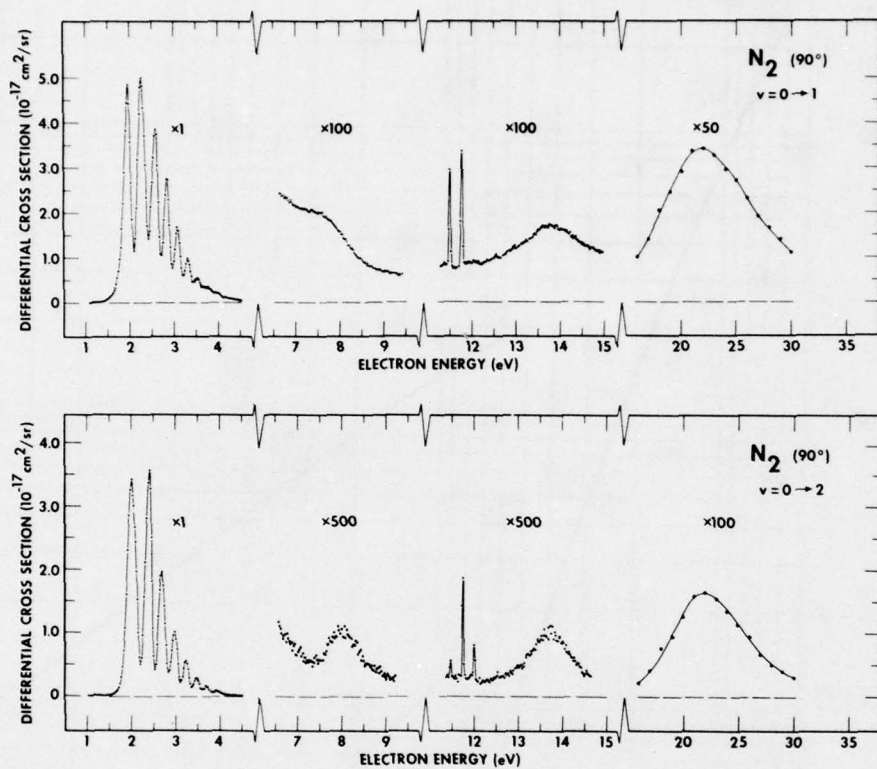
Accuracy:

These data are theoretical cross sections. There has been no test of the theory's validity at all; the data are likely to be very inaccurate at energies close to threshold.



Excitation of Lithium Ions by Electrons:
 $e + \text{Li}^+(1^1\text{S}) \rightarrow e + \text{Li}^+(2^1\text{S}, 2^1\text{P}, 2^3\text{S})$

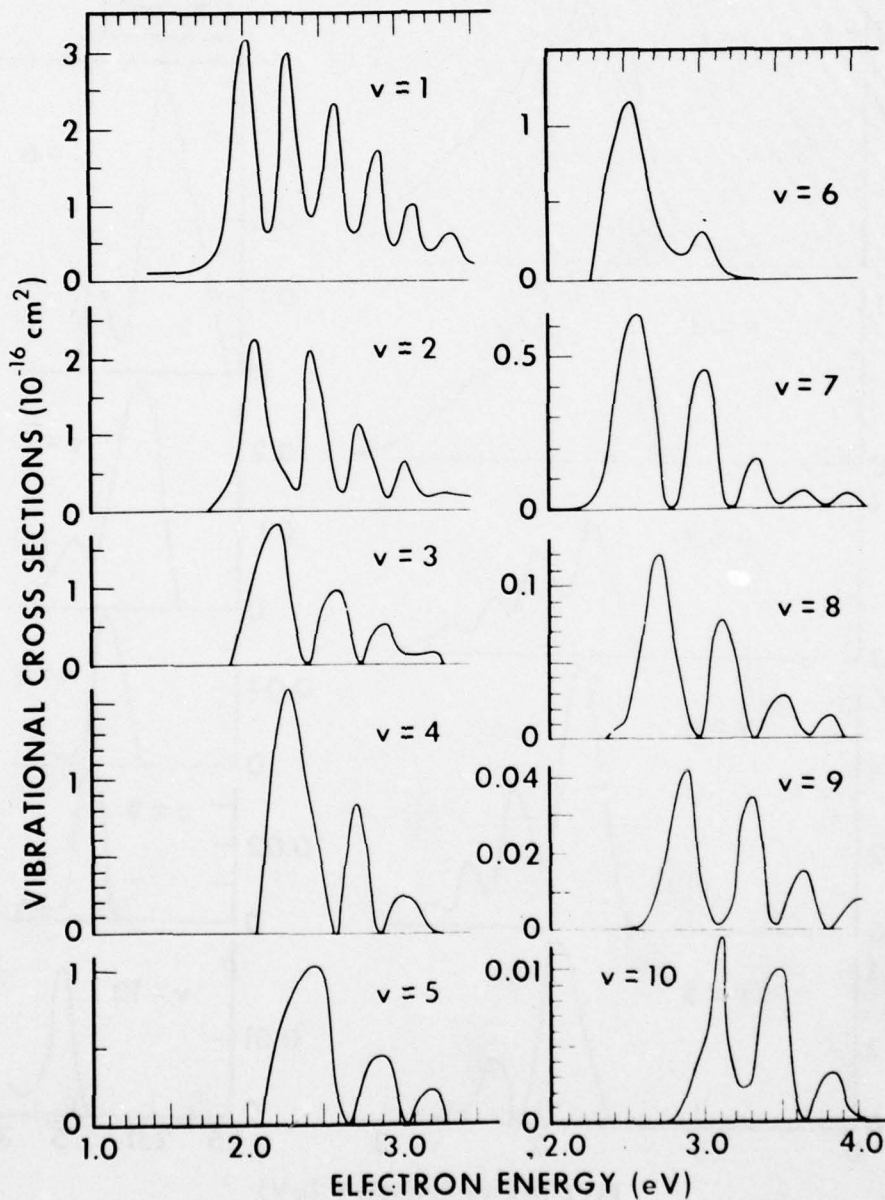
Graphical Data C-2.46.



Graphical Data C-2.47.

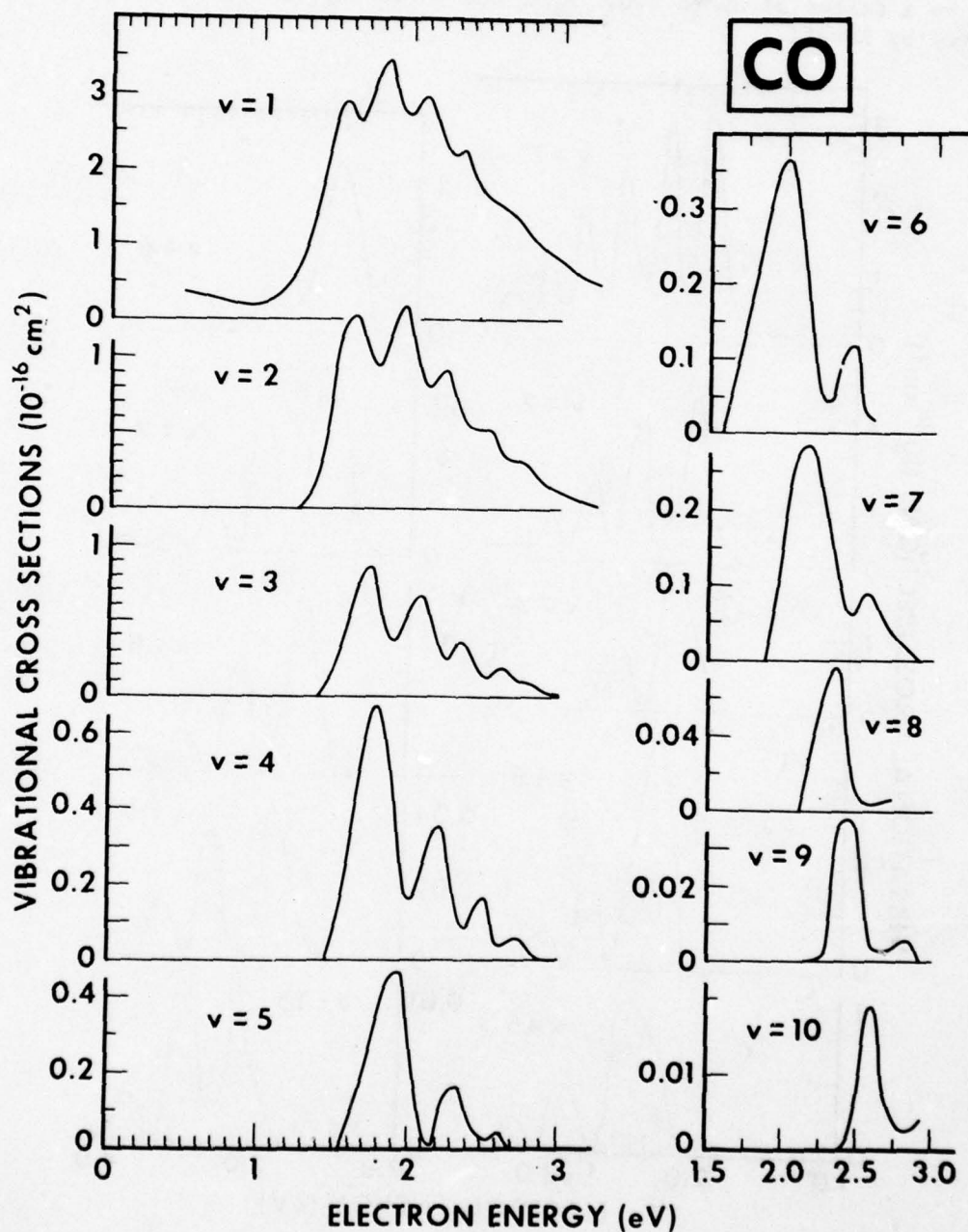
Global view of vibrational excitation in N_2 to $v = 1$ and $v = 2$ in the energy range 1 - 30 eV. (Electron impact). Data of S.F. Wong and G.J. Schulz, presented in G.J. Schulz, "A Review of Vibrational Excitation of Molecules by Electron Impact at Low Energies," in G. Bekefi (Ed.) "Principles of Laser Plasmas", pg 34, Wiley, N.Y. (1976).

Vibrational cross sections to $v = 1$ to 10 in N_2 . (Electron impact). The data plotted here are from Schulz (1964) for $v = 1$ to 6 and from Boness and Schulz (1973) for $v = 7$ to 10, normalized to the value given by Spence, Mauer and Schulz (1972). A digitized listing has been assembled by Kieffer (1973). The absolute values shown here may be too low by a factor of up to two. From the review by Schulz in the book edited by Bekefi.

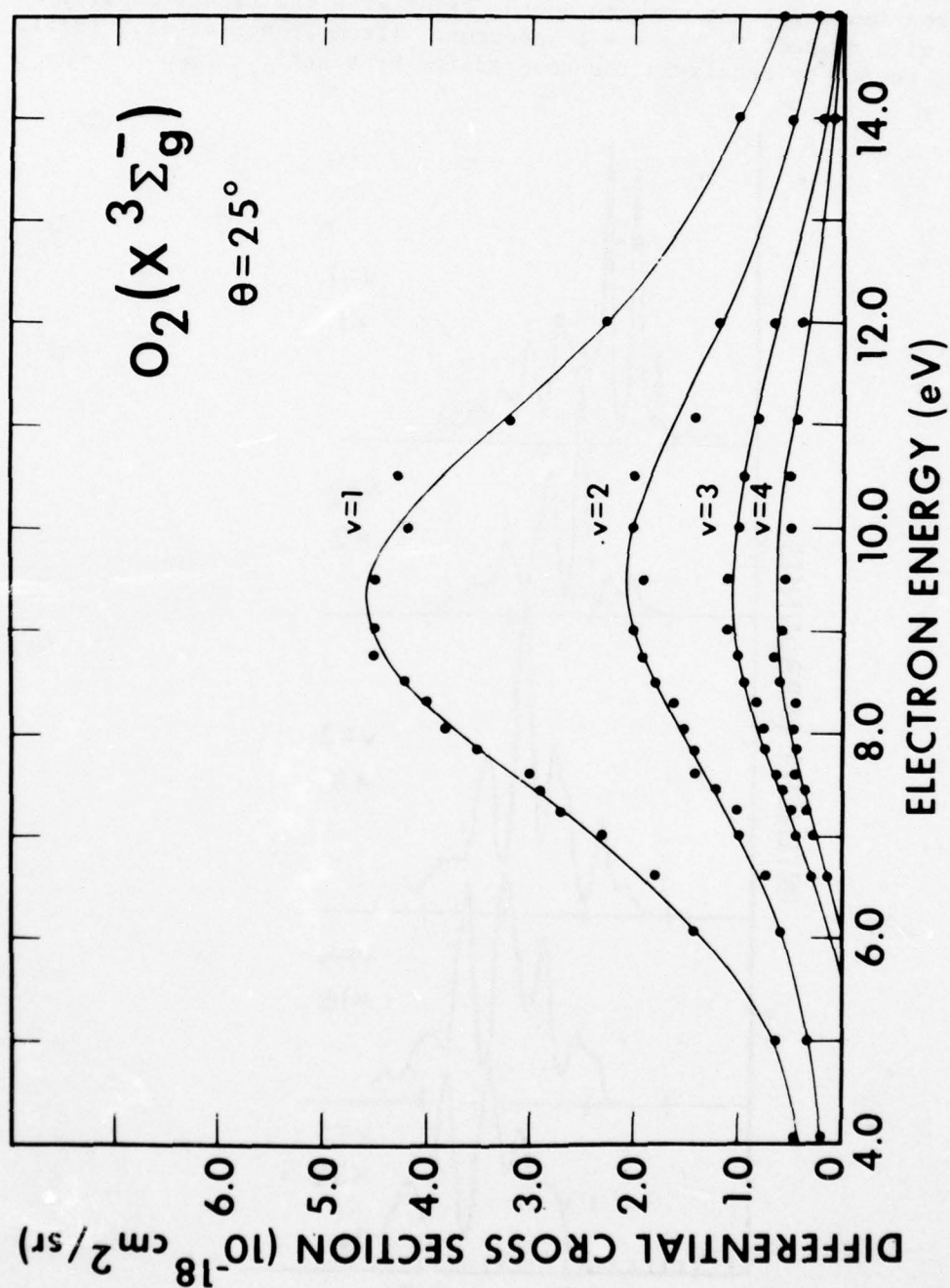


Graphical Data C-2.48.

Vibrational cross sections for $v = 1$ to 10 in CO. (Electron impact). The data are taken from Ehrhardt, et al. (1968) for $v = 1$ to 7 and from Boness and Schulz (1973) for $v = 8$ to 10. Absolute values are taken from Ehrhardt et al. (1968) as listed by Kieffer (1973). From the review by Schulz in the book edited by Bekefi.



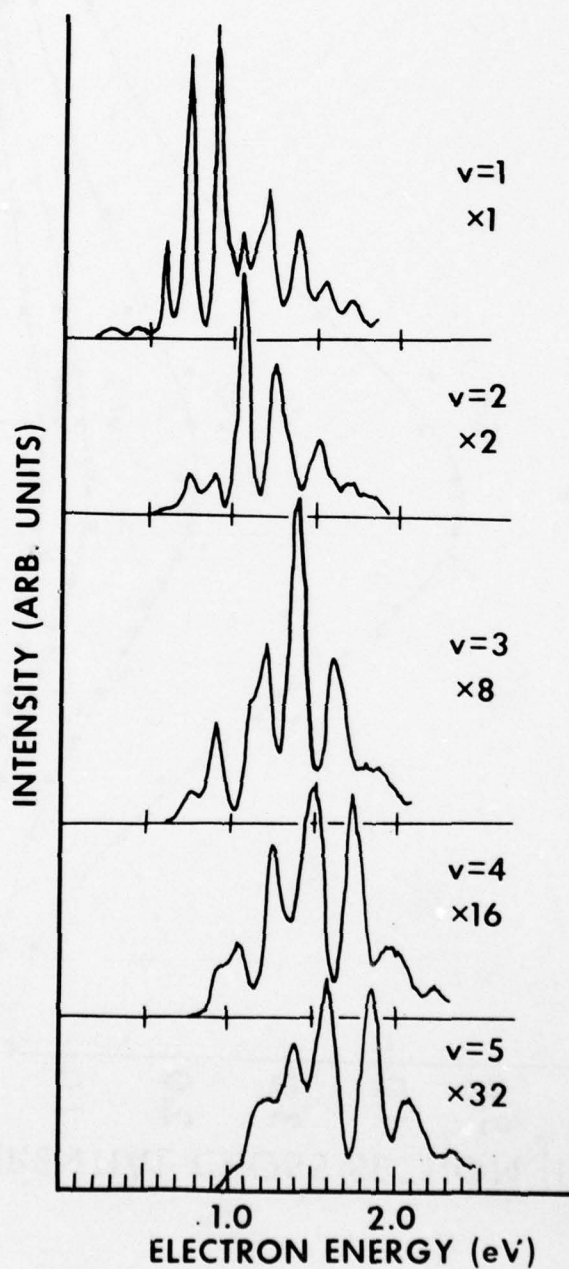
Graphical Data C-2.49.



Graphical Data C-2.50

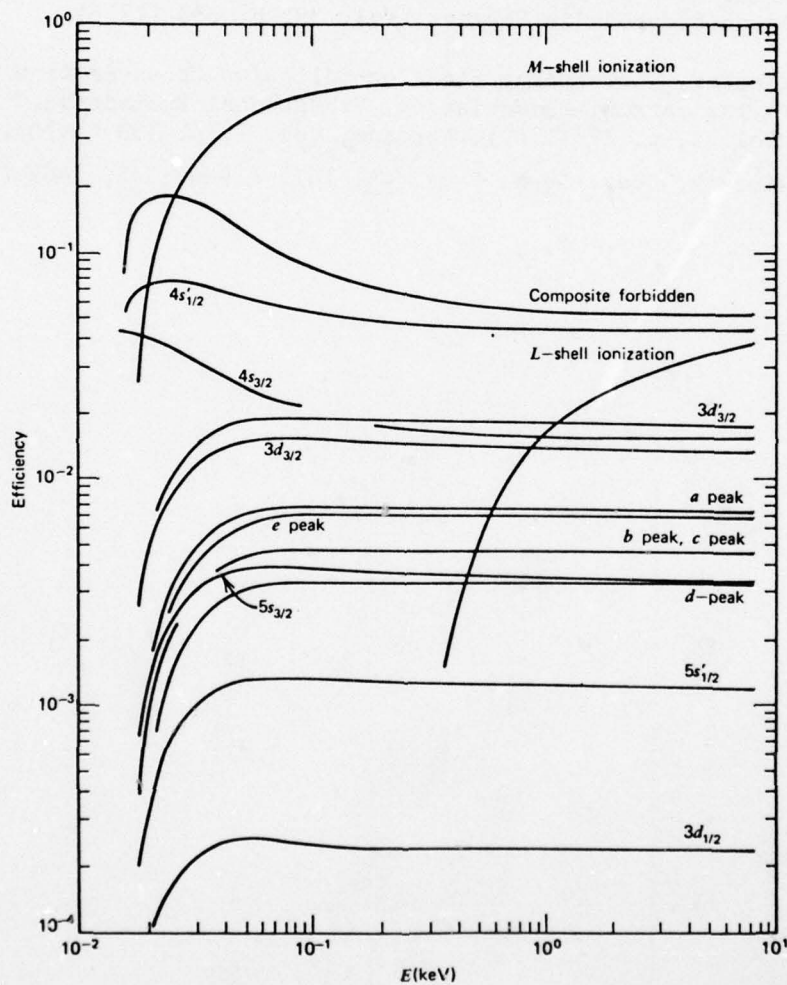
Vibrational excitation of O_2 in the energy range 4 - 14 eV. (Electron impact). S.F. Wong and G.J. Schulz, Phys. Rev. Letters, 31, 969 (1973).

Energy dependence of the differential cross section for vibrational excitation to $v = 1$ to 5 in NO, at a scattering angle of 40° . (Electron impact). The numbers on the right give the signal amplification with respect to the $v = 1$ spectrum. (From Tronc, et al., 1975). See the review by Schulz in the book edited by Bekefi.



Graphical Data C-2.51.

Calculated ionization and excitation efficiencies in argon as a function of primary electron energy. (From Peterson and Allen, 1972). See C.W. Werner and E.V. George, "Excimer Lasers", in "Principles of Laser Plasmas" (G. Bekefi, Ed.), Wiley, N. Y. (1976).



Graphical Data C-2.52.

C-3. DISSOCIATION BY ELECTRON IMPACT
General References

- D C.F. Barnett, J.A. Ray, E. Ricci, I. Wilker, E.W. McDaniel, E.W. Thomas and H.B. Gilbody, "Atomic Data for Controlled Fusion Research," Controlled Fusion Atomic Data Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee. (Feb., 1977). Reports ORNL 5206 and 5207, 680 pages.
- D,R K.T. Dolder and B. Peart, "Collisions Between Electrons and Ions," Reports on Progress in Physics, Vol. 39, p. 693 (1976).
- D,R L.J. Kieffer, "Low-Energy Electron-Collision Cross-Section Data, Part I: Ionization, Dissociation, Vibrational Excitation," Atomic Data, Vol. 1, p. 19 (1969), Erratum, Vol. 1, p. 359 (1970).
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C-3. DISSOCIATION BY ELECTRON IMPACT

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Tabular Data C-3.1.
Cross Sections for the Dissociation of O_2^+ Ions
and H_2 Molecules by Electron Impact

Energy (eV)	Cross Sections for Dissociation (cm^2)	
	$e + O_2^+$	$e + H_2$
9.0 E 00		7.0 E-18
1.0 E 01		2.5 E-17
1.2 E 01		6.5 E-17
1.5 E 01		8.8 E-17
1.7 E 01	2.20 E-16	8.8 E-17
2.0 E 01	2.30 E-16	8.0 E-17
3.0 E 01	2.80 E-16	3.8 E-17
4.0 E 01	3.20 E-16	2.0 E-17
5.0 E 01	3.43 E-16	1.1 E-17
6.0 E 01	3.58 E-16	5.0 E-18
7.5 E 01	3.64 E-16	1.0 E-18
1.0 E 02	3.52 E-16	
1.5 E 02	3.30 E-16	
2.0 E 02	2.99 E-16	
2.5 E 02	2.73 E-16	
4.0 E 02	2.11 E-16	
5.0 E 02	1.88 E-16	

References:

O_2^+ : B. Van Zyl and G.H. Dunn, Phys. Rev. 163, 43 (1967).

H_2 : S.J.B. Corrigan, J. Chem. Phys. 43, 4381 (1965).

Accuracy:

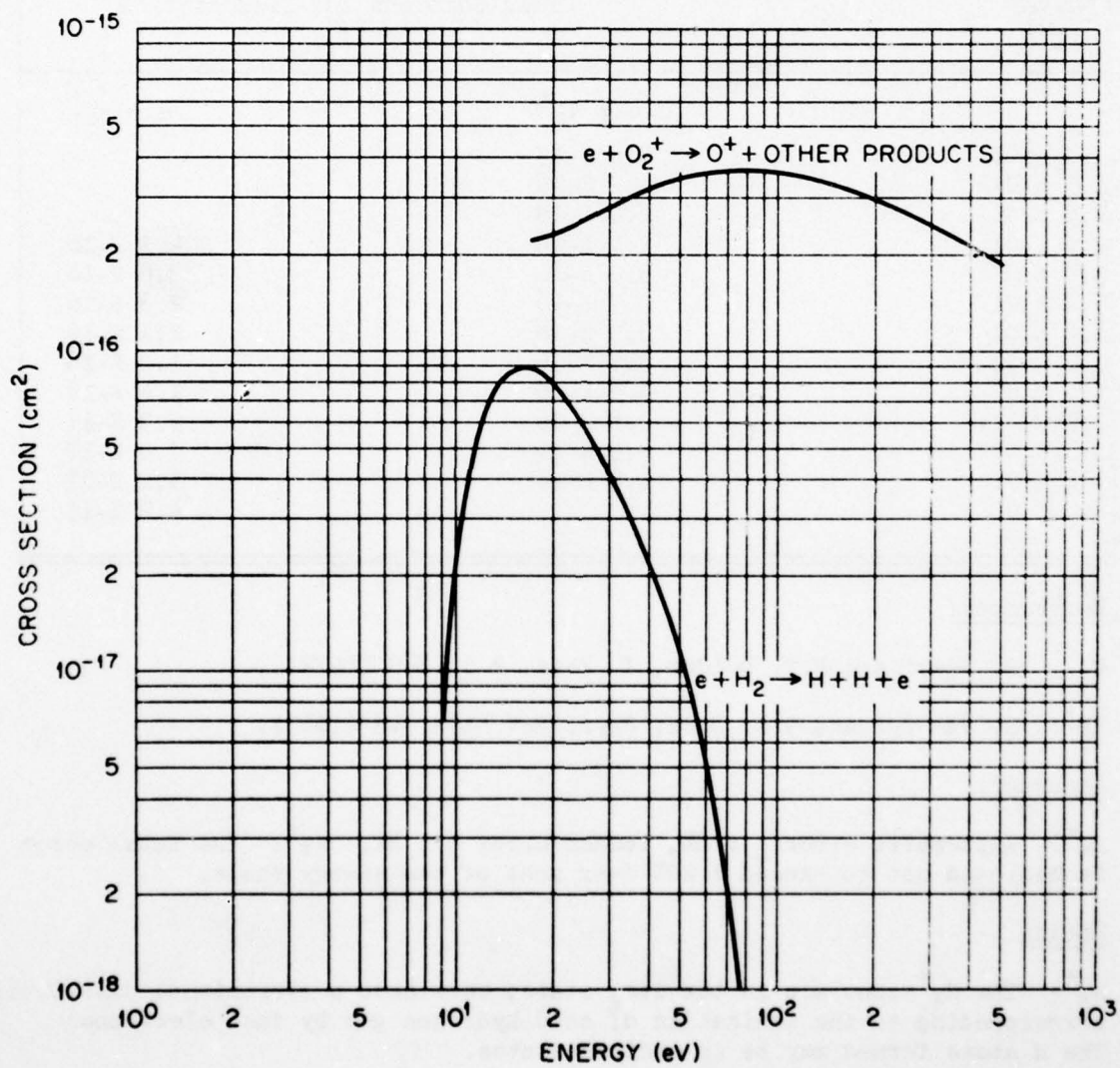
O_2^+ : The total error is believed not to exceed $\pm 20\%$ over most of the energy scale.

H_2 : The total error is believed not to exceed $\pm 50\%$.

Note:

O_2^+ : The target O_2^+ ions are typical of those formed by bombardment of O_2 by high (150 eV) energy electrons in a low-pressure (10^{-3} torr) ion source, and may thus be a mixture of ground- and excited-state molecular ions.

Cross Sections for the Dissociation of O_2^+ Ions
and H_2 Molecules by Electron Impact



Graphical Data C-3.2.

Tabular Data C-3.3.

Cross Sections for the Dissociation Reactions $e + H_2^+ \rightarrow H^+ + H + e$
and $e + N_2^+ \rightarrow N^+ + \text{Other Products}$

Energy (eV)	Cross Sections for Dissociation (cm ²)	
	$e + N_2^+$	$e + H_2^+$
1.0 E 01	3.6 E-17	
1.5 E 01	1.2 E-16	
2.0 E 01	2.0 E-16	
2.5 E 01	2.6 E-16	4.3 E-16
3.0 E 01	3.0 E-16	3.8 E-16
5.0 E 01	3.7 E-16	2.8 E-16
8.0 E 01	3.9 E-16	2.1 E-16
1.0 E 02	3.7 E-16	1.8 E-16
1.5 E 02	3.5 E-16	1.4 E-16
2.5 E 02	2.8 E-16	9.3 E-17
3.5 E 02	2.3 E-16	7.0 E-17
5.0 E 02	1.8 E-16	5.2 E-17
7.0 E 02		4.2 E-17

References:

H_2^+ : B. Peart and K.T. Dolder, J. Phys. B 5, 860 (1972).

N_2^+ : B. Van Zyl and G.H. Dunn, Phys. Rev. 163, 43 (1967).

Accuracy:

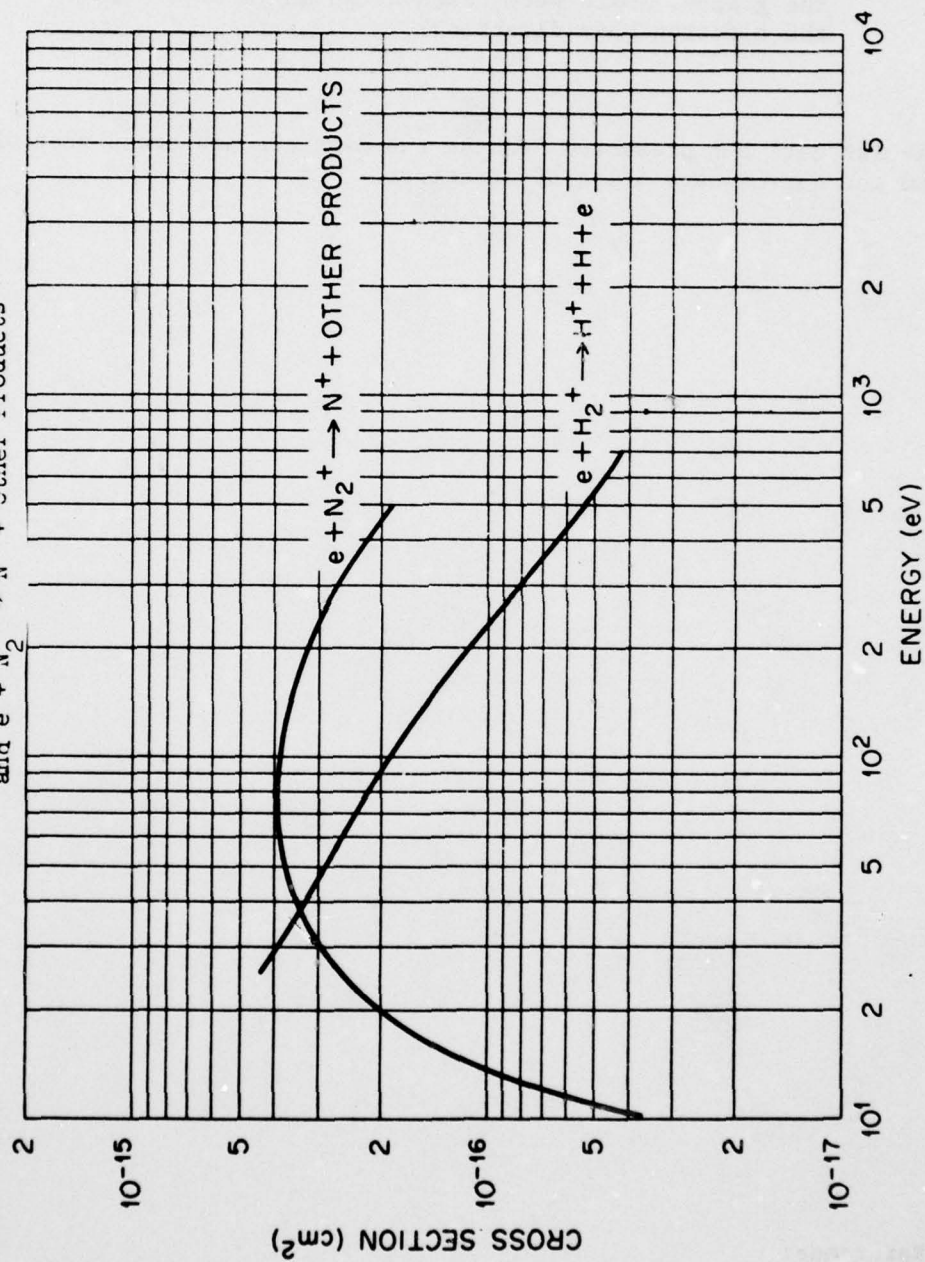
H_2^+ : systematic error $\leq \pm 8\%$, random error $\leq \pm 8\%$. N_2^+ : The Total error is believed not to exceed $\pm 20\%$ over most of the energy scale.

Notes:

H_2^+ : The H_2^+ ions are in the $1s\sigma_g$ state; they have a vibrational distribution corresponding to the ionization of cold hydrogen gas by fast electrons. The H atoms formed may be in excited states.

N_2^+ : The target N_2^+ ions are typical of those formed by bombardment of N_2 by high (150 eV) energy electrons in a low-pressure (10^{-3} torr) ion source, and may thus be a mixture of ground- and excited-state molecular ions.

Cross Sections for the Dissociation Reactions $e + H_2^+ \rightarrow H^+ + H + e$
and $e + N_2^+ \rightarrow N^+ + \text{Other Products}$



Graphical Data C-3.4.

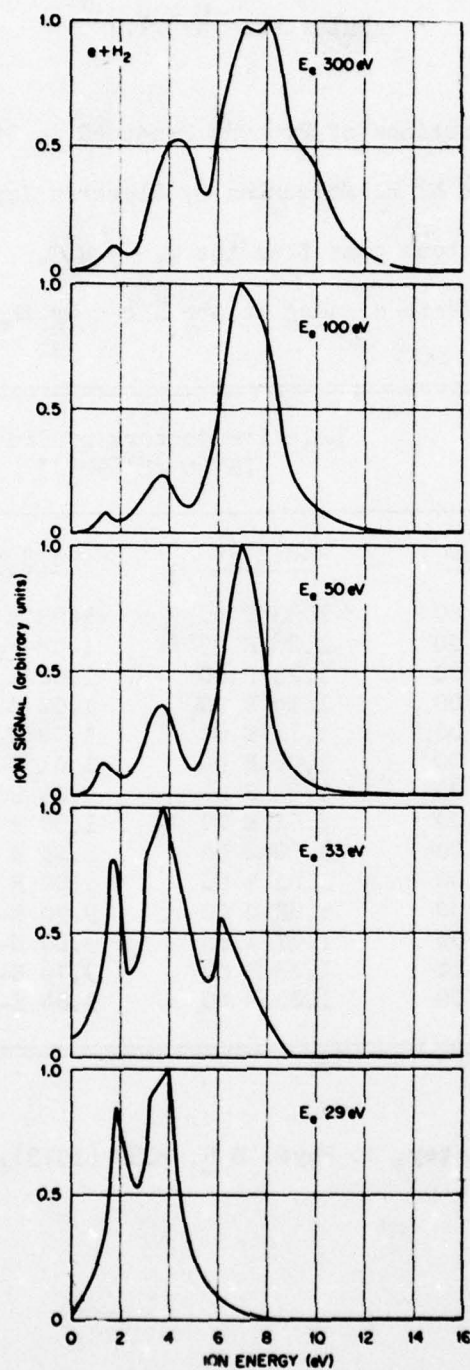
Graphical and Tabular Data C-3.5.

Energy spectra of protons obtained in dissociative ionization of H_2 molecules by electron impact (The incident electron energies are indicated alongside the graphs. Data were taken at an angle of 27° to the electron beam direction).

Tabular data not presented because the data are not cross sections, and the curves have a lot of structure.

Reference:

A. Crowe and J.W. McConkey, Phys. Rev. Letts. 31, 192 (1973).



Energy Spectra of Protons Obtained in Dissociative
Ionization of H_2 Molecules by Electron Impact
Graphical Data C-3.6.

Tabular Data C-3.7.

Angular Distributions of Protons Produced in Dissociative

Ionization of H_2 Molecules by Electron Impact

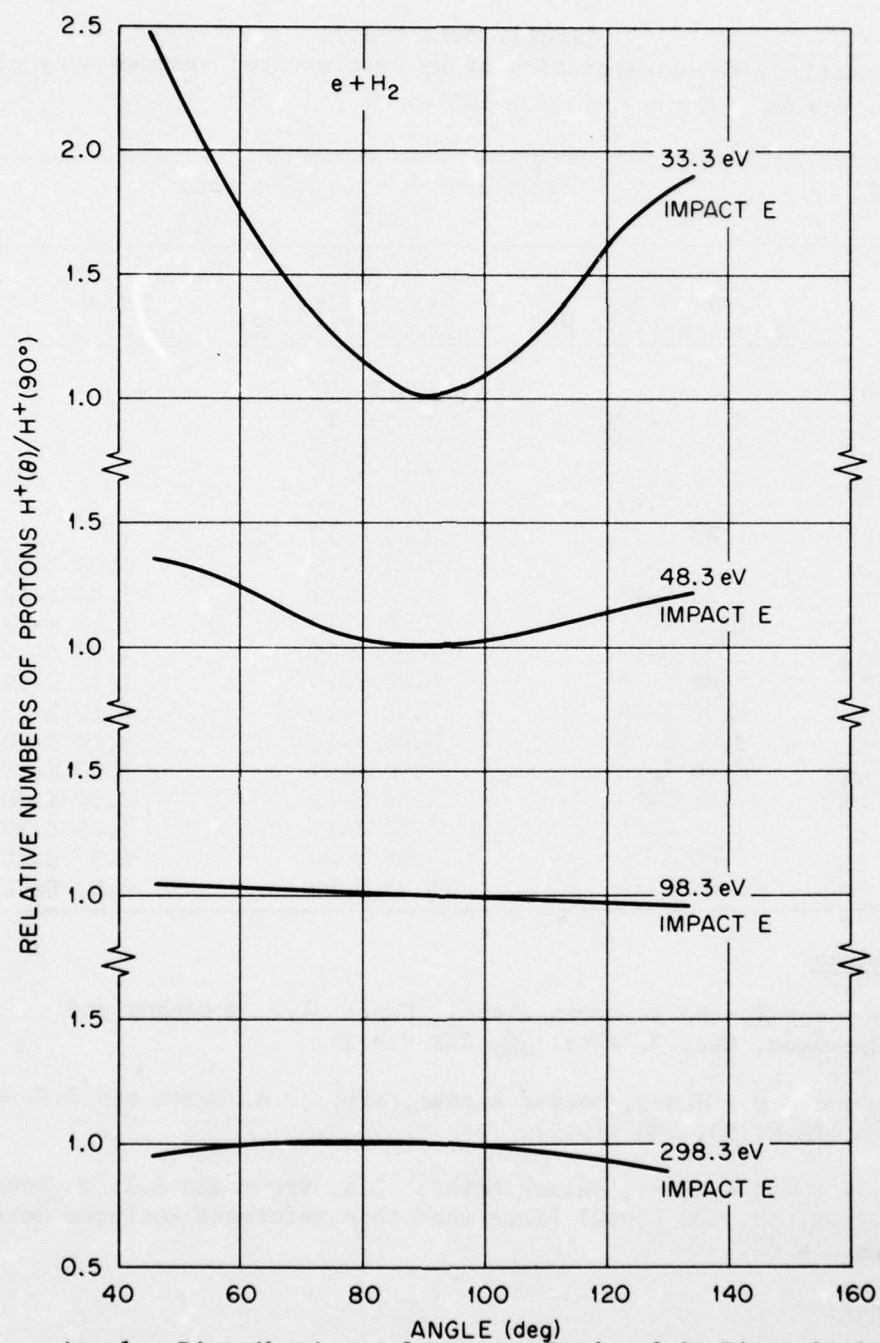
(the protons come from the $2\Sigma_u^+ / H_2^+$.

The incident electron energies are shown by the graphs.)

Angle (deg)	Relative Numbers of Protons [$H^+(\theta)/H^+(90^\circ)$]			
	33.3 eV	48.3 eV	98.3 eV	298.3 eV
5.0 E 01	2.22 E 00	1.33 E 00	1.03 E 00	9.70 E-01
5.5 E 01	1.98 E 00	1.28 E 00	1.02 E 00	9.80 E-01
6.0 E 01	1.76 E 00	1.23 E 00	1.02 E 00	9.93 E-01
6.5 E 01	1.57 E 00	1.18 E 00	1.02 E 00	1.00 E 00
7.0 E 01	1.40 E 00	1.11 E 00	1.02 E 00	1.01 E 00
7.5 E 01	1.26 E 00	1.06 E 00	1.01 E 00	1.01 E 00
8.0 E 01	1.15 E 00	1.03 E 00	1.00 E 00	1.01 E 00
8.5 E 01	1.06 E 00	1.01 E 00	1.00 E 00	1.00 E 00
9.0 E 01	1.00 E 00	1.00 E 00	1.00 E 00	1.00 E 00
9.5 E 01	1.03 E 00	1.01 E 00	1.00 E 00	9.90 E-01
1.0 E 02	1.10 E 00	1.02 E 00	9.90 E-01	9.80 E-01
1.1 E 02	1.30 E 00	1.07 E 00	9.80 E-01	9.60 E-01
1.2 E 02	1.62 E 00	1.13 E 00	9.76 E-01	9.26 E-01
1.3 E 02	1.84 E 00	1.20 E 00	9.64 E-01	8.80 E-01

Reference:

A. Crowe and J.W. McConkey, J. Phys. B 6, 2088 (1973).



Angular Distributions of Protons Produced in Dissociative Ionization of H_2 Molecules by Electron Impact

(The protons come from the $^2\Sigma_u^+ / H_2^+$).

The incident electron energies are shown by the graphs).
Graphical Data C-3.8.

Tabular Data C-3.9.

Cross sections for dissociation of H_2 into excited fragments by electron impact: $e + H_2 \rightarrow e + H + H(2p, n=3, n=4)$

Energy (eV)	Experimental Cross Sections (cm^2)		
	H(2p) Lyman Alpha Emission (1216 Å)	H(n=3) Balmer Alpha Emission (6563 Å)	H(n=4) Balmer Beta Emission (4431 Å)
1.0 E 01		3.4 E-19	
1.5 E 01	2.8 E-18	6.60 E-19	
2.0 E 01	9.1 E-18	6.70 E-19	
2.5 E 01	1.08 E-17	7.70 E-19	
3.0 E 01	1.17 E-17	8.70 E-19	
4.0 E 01	1.28 E-17	9.20 E-19	
6.0 E 01	1.32 E-17	9.60 E-19	1.88 E-19
8.0 E 01	1.30 E-17	9.30 E-19	1.82 E-19
1.0 E 02	1.22 E-17	8.80 E-19	1.70 E-19
1.5 E 02	1.03 E-17	7.20 E-19	1.38 E-19
2.0 E 02	8.80 E-18	6.00 E-19	1.12 E-19
4.0 E 02	5.08 E-18	3.50 E-19	6.10 E-20
6.0 E 02	3.63 E-18	2.48 E-19	4.10 E-20
8.0 E 02	2.90 E-18	1.90 E-19	3.10 E-20
1.0 E 03	2.45 E-18	1.56 E-19	2.50 E-20
2.0 E 03	1.42 E-18	8.50 E-20	1.25 E-20
4.0 E 03	8.00 E-19	4.65 E-20	6.5 E-21
6.0 E 03	5.64 E-19	3.35 E-20	4.5 E-21

References:

$e + H_2 \rightarrow e + H + H(2p, \text{Lyman alpha})$, Exp.: J.W. McConkey and F.G. Donalson, Can. J. Phys. 50, 221 (1972).

$e + H_2 \rightarrow e + H + H(n=3, \text{Balmer alpha})$, Exp.: D.A. Vroom and F.J. de Heer, J. Chem. Phys. 50, 580 (1969).

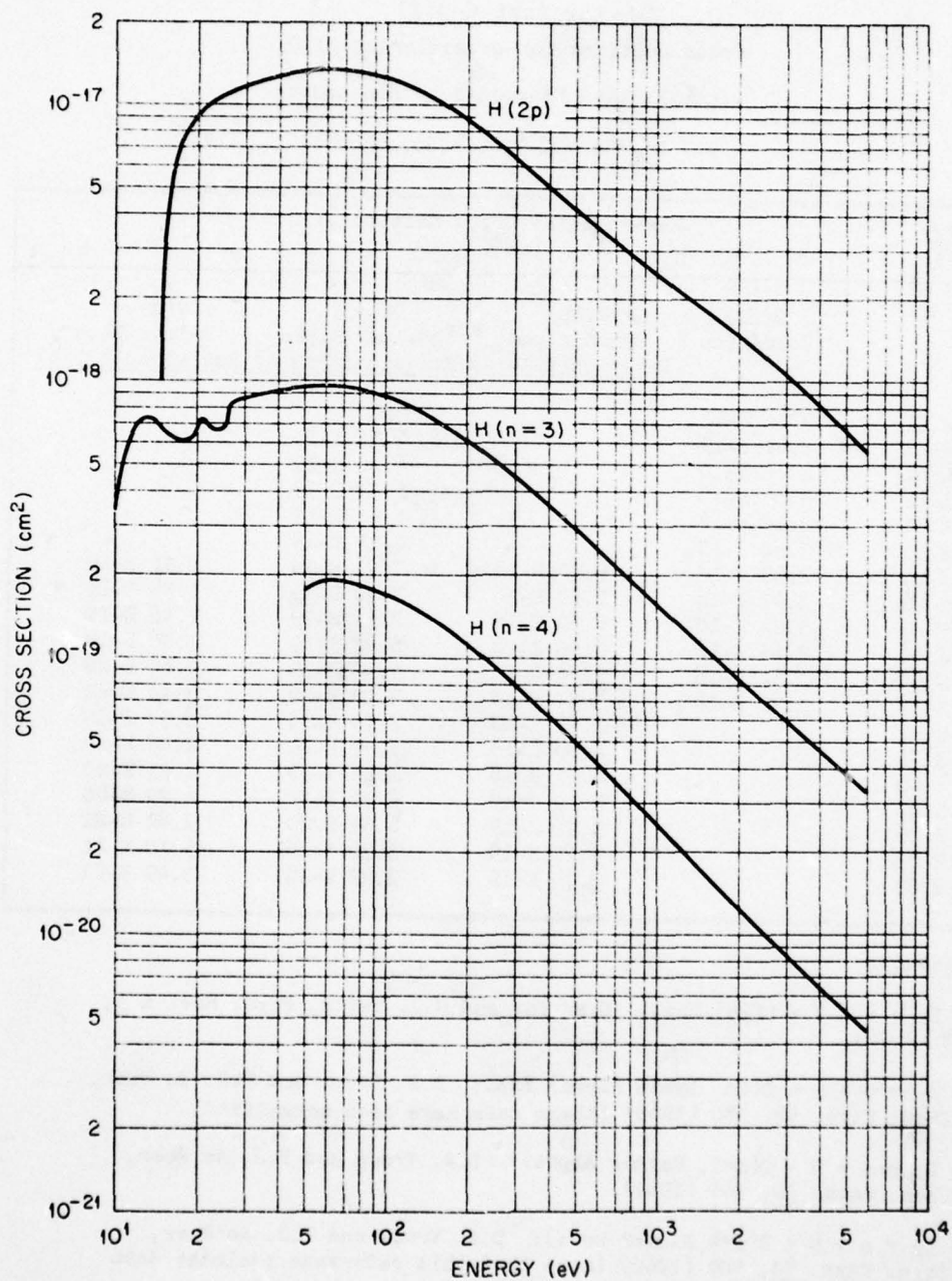
$e + H_2 \rightarrow e + H + H(n=4, \text{Balmer beta})$: D.A. Vroom and F.J. de Heer, J. Chem. Phys. 50, 580 (1969) [Note that this reference includes data through $n = 6$].

Accuracy:

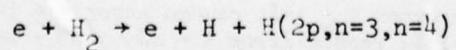
2p state - systematic error $< \pm 10\%$; random error $< \pm 2\%$.

$n = 3$ - systematic error $< \pm 12\%$; random error $< \pm 4\%$.

$n = 4$ - systematic error $< \pm 7\%$; random error $< \pm 4\%$.



Cross Sections for Dissociation of H_2 into
Excited Fragments by Electron Impact:



Graphical Data C-3.10.

Tabular Data C-3.11.
Cross Sections for Dissociation of D_2
Into Excited Fragments by Electrons:
 $e + D_2 \rightarrow e + D + D(2s, 2p, n=3, n=4)$

Energy (eV)	Experimental Cross Sections (cm^2)			
	D(2s) Formation	D(2p) Lyman Alpha <u>Emission(1216 Å)</u>	D(n=3) Balmer Alpha <u>Emission(6563 Å)</u>	D(n=4) Balmer Beta <u>Emission(4431 Å)</u>
1.4 E 01	9.0 E-21			
1.5 E 01	2.41 E-19		4.30 E-19	
2.0 E 01	2.70 E-18		4.20 E-19	
2.5 E 01	3.00 E-18		5.50 E-19	
3.0 E 01	3.10 E-18		5.82 E-19	
4.0 E 01	3.42 E-18		7.11 E-19	
6.0 E 01	3.45 E-18	9.60 E-18	7.90 E-19	1.51 E-19
8.0 F 01	3.42 E-18	9.00 E-18	7.90 E-19	1.54 E-19
1.0 E 02	3.24 E-18	8.30 E-18	7.52 E-19	1.46 E-19
1.5 E 02	2.85 E-18	6.90 E-18	6.47 E-19	1.18 E-19
2.0 E 02	2.52 E-18	5.80 E-18	5.40 E-19	9.60 E-20
4.0 E 02	1.70 E-18	3.57 E-18	3.03 E-19	5.16 E-20
6.0 E 02		2.55 E-18	2.10 E-19	3.37 E-20
8.0 E 02		2.00 E-18	1.55 E-19	2.48 E-20
1.0 E 03		1.67 E-18	1.25 E-19	1.95 E-20
1.5 E 03		1.19 E-18	8.52 E-20	1.29 E-20
2.0 E 03		9.20 E-19	6.55 E-20	9.80 E-21
4.0 E 03		5.20 E-19	3.30 E-20	5.10 E-21
6.0 E 03		3.74 E-19	2.42 E-20	3.49 E-21

References:

- $e + D_2 \rightarrow e + D + D(2s)$ Exp.: D.M. Cox and S.J. Smith, Phys. Rev. A 5, 2428 (1972).
- $e + D_2 \rightarrow e + D + D(2p, \text{Lyman Alpha})$ Exp.: D.A. Vroom and F.J. de Heer, J. Chem. Phys. 50, 580 (1969) [these data have been normalized]
- $e + D_2 \rightarrow e + D + D(n=3, \text{Balmer Alpha})$: D.A. Vroom and F.J. de Heer, J. Chem. Phys. 50, 580 (1969).
- $e + D_2 \rightarrow e + D + D(n=4 \text{ Balmer Beta})$: D.A. Vroom and F.J. de Heer, J. Chem. Phys. 50, 580 (1969) [note that this reference includes data through $n=6$].

Accuracy:

2s state - systematic error $< + 14\%$; random error $< + 5\%$. 2p state - systematic error $< + 15\%$; random error $< + 5\%$. $n=3$ - systematic error $< + 12\%$; random error $< + 4\%$. $n=6$ - systematic error $< + 7\%$; random error $< + 4\%$.

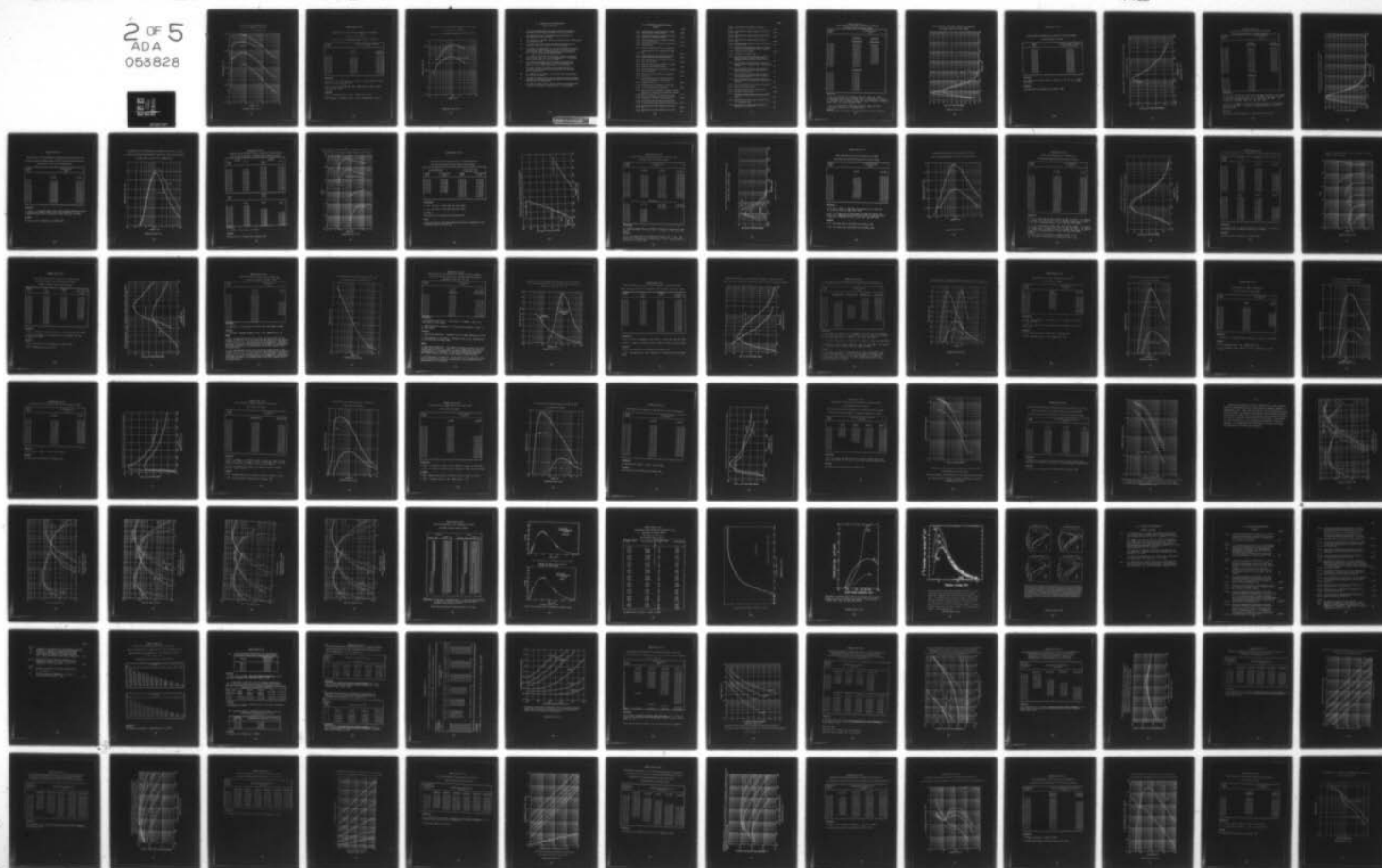
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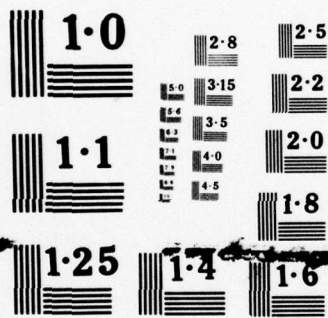
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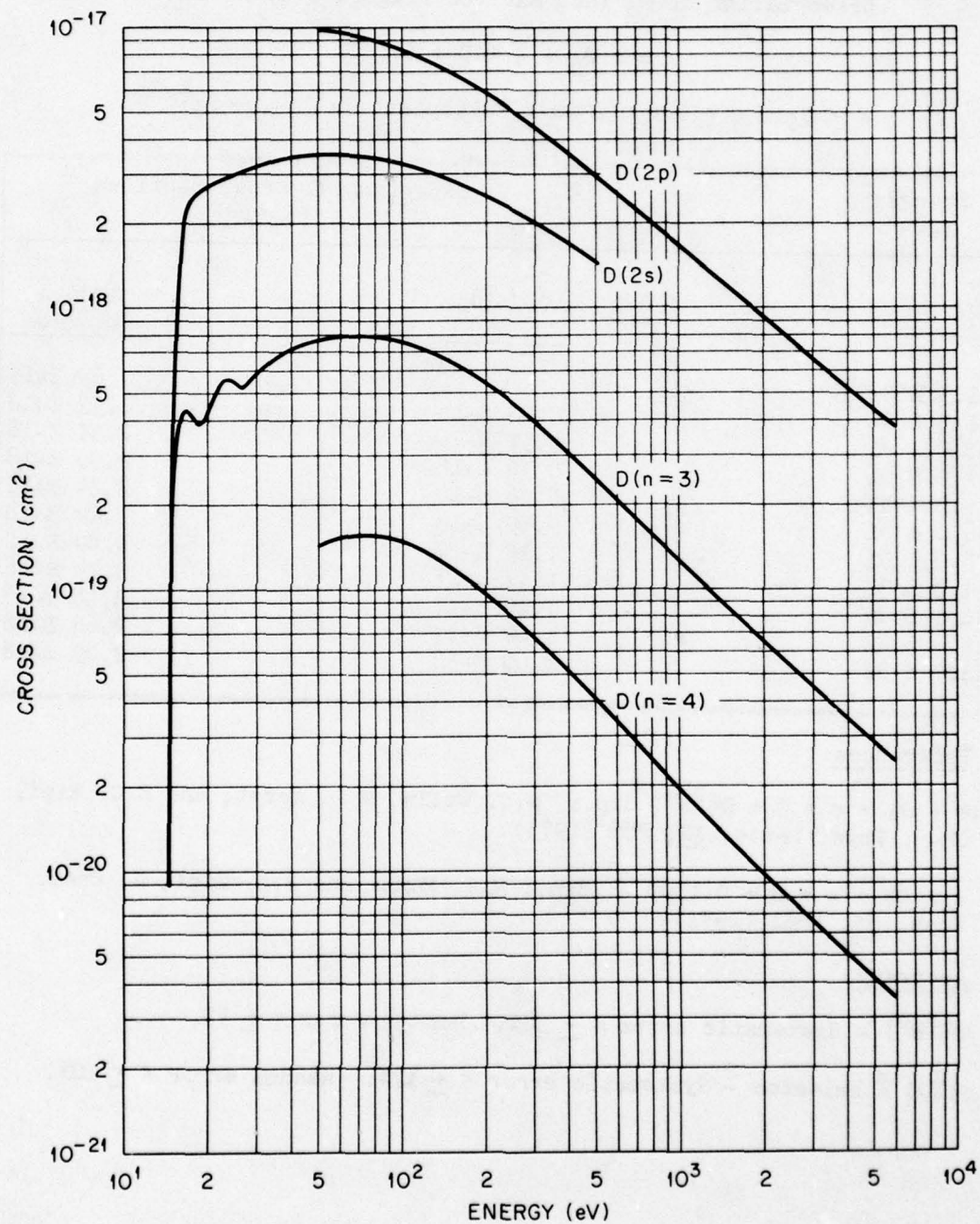
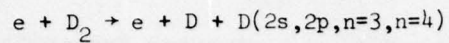




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MICROCOPY RESOLUTION TEST CHART

Cross Sections for Dissociation of D_2

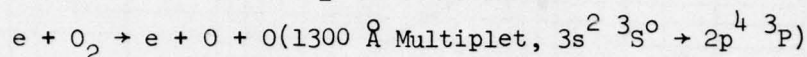
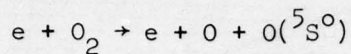
Into Excited Fragments by Electrons:



Graphical Data C-3.12.

Tabular Data C-3.13.

Dissociation of O_2 into Excited Fragments by Electrons:



Energy (eV)	Experimental Cross Sections (cm ²)	
	$O(^5S^0)$	1300 Å Emission
1.5 E 01		7.65 E-19
2.0 E 01	2.53 E-18	1.42 E-18
3.0 E 01	4.57 E-18	2.37 E-18
4.0 E 01	6.59 E-18	2.95 E-18
5.0 E 01	8.36 E-18	3.34 E-18
6.0 E 01	9.89 E-18	3.60 E-18
8.0 E 01	1.12 E-17	3.80 E-18
1.0 E 02	1.17 E-17	3.74 E-18
1.5 E 02	1.12 E-17	3.18 E-18
2.0 E 02	1.02 E-17	2.68 E-18
3.0 E 02	8.00 E-18	2.09 E-18

References:

$e + O_2 \rightarrow e + O + O(^5S^0)$ Exp.: W.C. Wells, W.L. Borst, and E.C. Zipf, Chem. Phys. Letts. 12, 288 (1971).

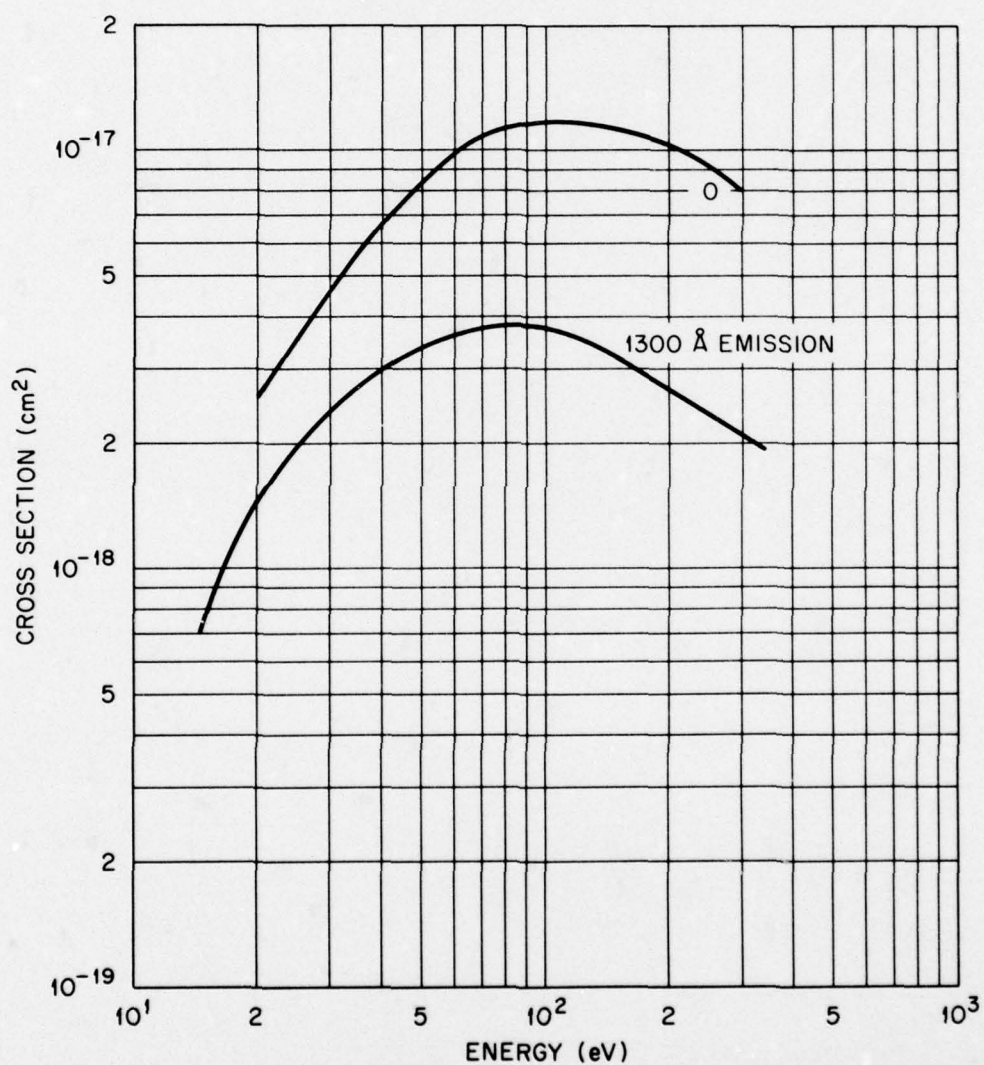
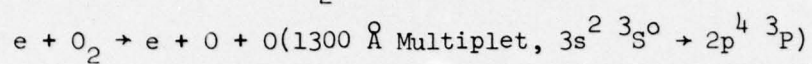
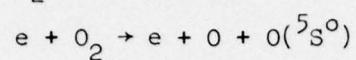
$e + O_2 \rightarrow e + O + O(1300 \text{ \AA})$ Exp.: M.J. Mumma and E.C. Zipf, J. Chem. Phys. 55, 1661 (1971).

Accuracy:

$O(^5S^0)$ - Systematic error < $\pm 50\%$. Random error < $\pm 5\%$.

1300 Å Emission - Systematic error < $\pm 17\%$. Random error < $\pm 10\%$.

Dissociation of O_2 into Excited Fragments by Electrons:



Graphical Data C-3.14.

C-4. IONIZATION BY ELECTRON IMPACT

General References

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- R.A. Bonham and M. Fink, "High Energy Electron Scattering," Van Nostrand Reinhold, New York (1974).
- D,R P.G. Burke and J.F. Williams, "Electron Scattering by Atoms and Molecules," *Physics Reports* (1978).
- D,R K.T. Dolder and B. Peart, "Collisions Between Electrons and Ions," *Reports on Progress in Physics*, Vol. 39, pg. 693 (1976).
- D,R H. Ehrhardt, K.H. Hesselbacher, K. Jung, and K. Willmann, "Differential Cross Sections in Electron Impact Ionization," in E.W. McDaniel and M.R.C. McDowell (Eds.), "Case Studies in Atomic Collision Physics," Vol. 2, pg. 161, North-Holland, Amsterdam (1972).
- D,R L.J. Kieffer and G.H. Dunn, "Electron Impact Ionization Cross-Section Data for Atoms, Atomic Ions, and Diatomic Molecules: I. Experimental Data," *Rev. Mod. Phys.* Vol. 38, pg. 1 (1966).
- D,R L.J. Kieffer, "Low-Energy Electron- Collision Cross-Section Data Part I: Ionization, Dissociation, Vibrational Excitation," *Atomic Data* Vol. 1, pg. 19 (1969), Erratum, Vol. 1, pg. 359 (1970).
- M. Inokuti, "Inelastic Collisions of Fast Charged Particles with Atoms and Molecules - The Bethe Theory Revisited," *Rev. Mod. Phys.*, Vol. 43, pg. 297 (1971).
- D,R I.E. McCarthy, and E. Weigold, "(e,2e) Spectroscopy," *Physics Reports*, Vol. 27C, pg. 275 (1976).
- D,R C.B. Opal, E.C. Beaty, and W.K. Peterson, "Tables of Energy and Angular Distributions of Electrons Ejected from Simple Gases by Electron Impact," *JILA Report No. 108* (26 May 1971).
- D C.B. Opal, E.C. Beaty, and W.K. Peterson, "Tables of Secondary-Electron-Production Cross Sections," *Atomic Data*, Vol. 4, pg. 209 (1972).

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Tabular Data C-4.1.
Cross Sections σ for Single Ionization of Hydrogen
and Oxygen Atoms by Electron Impact

Energy (keV)	Cross Sections (cm ²)	
	<u>e+H→H⁺+2e</u>	<u>e+O→O⁺+2e</u>
	<u>Experimental</u>	<u>Experimental</u>
2.0 E-02	3.00 E-17	5.60 E-17
2.5 E-02	4.37 E-17	8.70 E-17
3.0 E-02	5.27 E-17	1.08 E-16
4.0 E-02	6.24 E-17	1.32 E-16
6.0 E-02	7.66 E-17	1.52 E-16
8.0 E-02	6.59 E-17	1.58 E-16
1.0 E-01	6.08 E-17	1.55 E-16
1.5 E-01	4.80 E-17	1.42 E-16
2.0 E-01	4.13 E-17	1.31 E-16
2.5 E-01	3.57 E-17	1.22 E-16
3.0 E-01	3.19 E-17	1.10 E-16
4.0 E-01	2.51 E-17	9.26 E-17
6.0 E-01	1.80 E-17	
8.0 E-01	1.41 E-17	
	<u>Theoretical</u>	
1.0 E 00	1.2 E-17	
5.0 E 00	2.8 E-18	
1.0 E 01	1.5 E-18	
5.0 E 01	3.9 E-19	
1.0 E 02	2.3 E-19	
5.0 E 02	1.0 E-19	
1.0 E 03	9.3 E-20	
5.0 E 03	9.7 E-20	
1.0 E 04	1.0 E-19	
5.0 E 04	1.2 E-19	
1.0 E 05	1.3 E-19	

References:

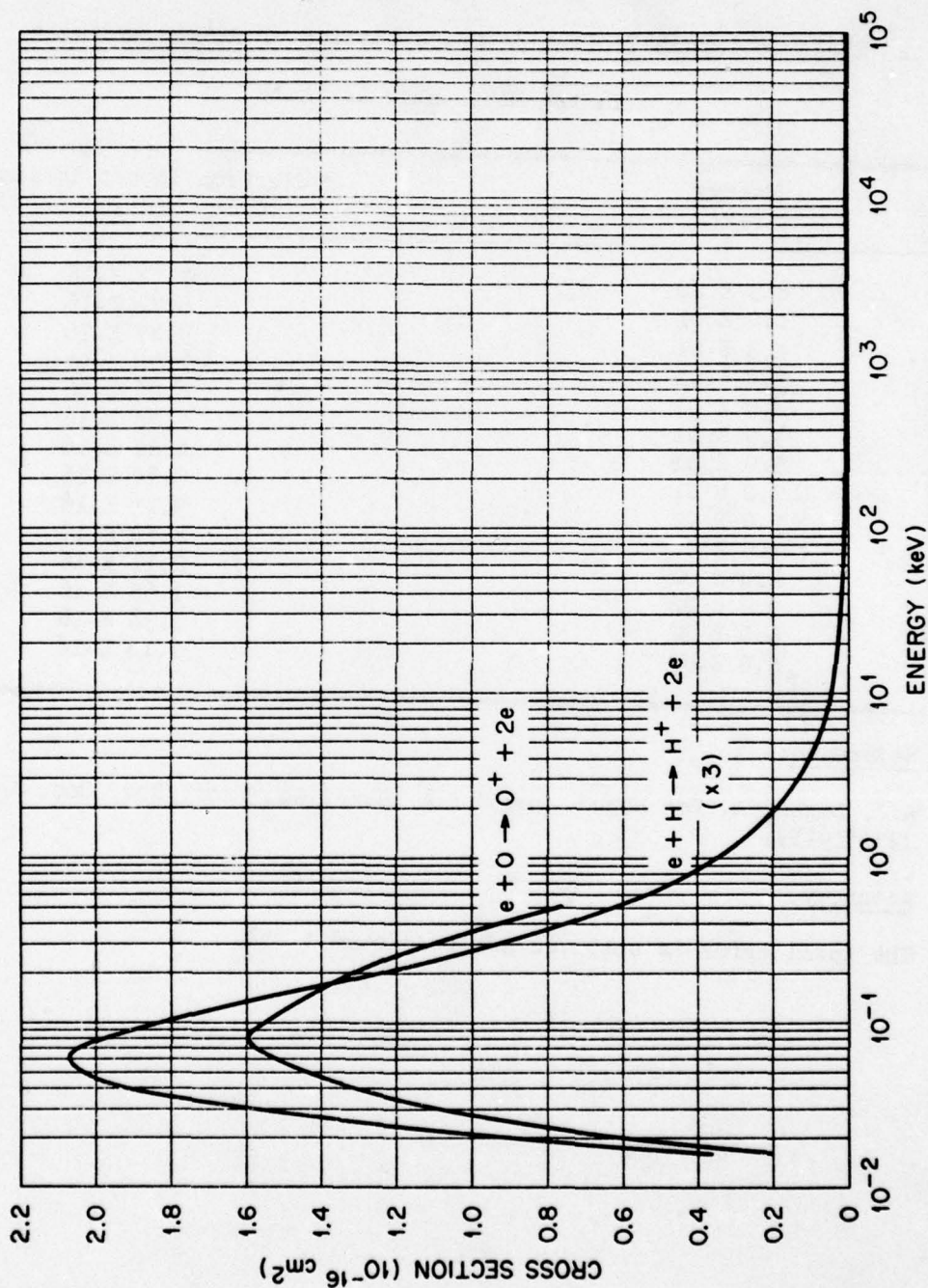
e + H: W.L. Fite and R.T. Brackmann, Phys. Rev. 112, 1141 (1958).
A. Boksenberg, Thesis, Univ. of London (1961). E.W. Rothe, L.L. Marino,
R.H. Neynaber, and S.M. Trujillo, Phys. Rev. 125, 582 (1962). M. Inokuti,
Argonne Natl. Lab. Report ANL-6769 (1963).

e + O: W.L. Fite and R.T. Brackmann, Phys. Rev. 113, 815 (1959).
A. Boksenberg, Thesis, Univ. of London (1961).

Accuracy:

The total error is believed not to exceed ± 15% for H and ± 30% for O.

Cross Sections σ for Single Ionization of Hydrogen
and Oxygen Atoms by Electron Impact



Graphical Data C-4.2.

Tabular Data C-4.3.

Electron Impact Ionization Cross Section of Atomic Hydrogen
in the Metastable 2s State

Energy (eV)	Electron Impact Ionization Cross Section (cm ²)
8.3 E 00	7.12 E-16
1.0 E 01	8.72 E-16
1.3 E 01	9.45 E-16
2.0 E 01	7.58 E-16
3.0 E 01	6.06 E-16
4.0 E 01	5.20 E-16
5.0 E 01	4.62 E-16
7.0 E 01	3.80 E-16
1.0 E 02	3.11 E-16
1.5 E 02	2.50 E-16
2.0 E 02	2.11 E-16
3.0 E 02	1.65 E-16
4.0 E 02	1.38 E-16
5.0 E 02	1.18 E-16

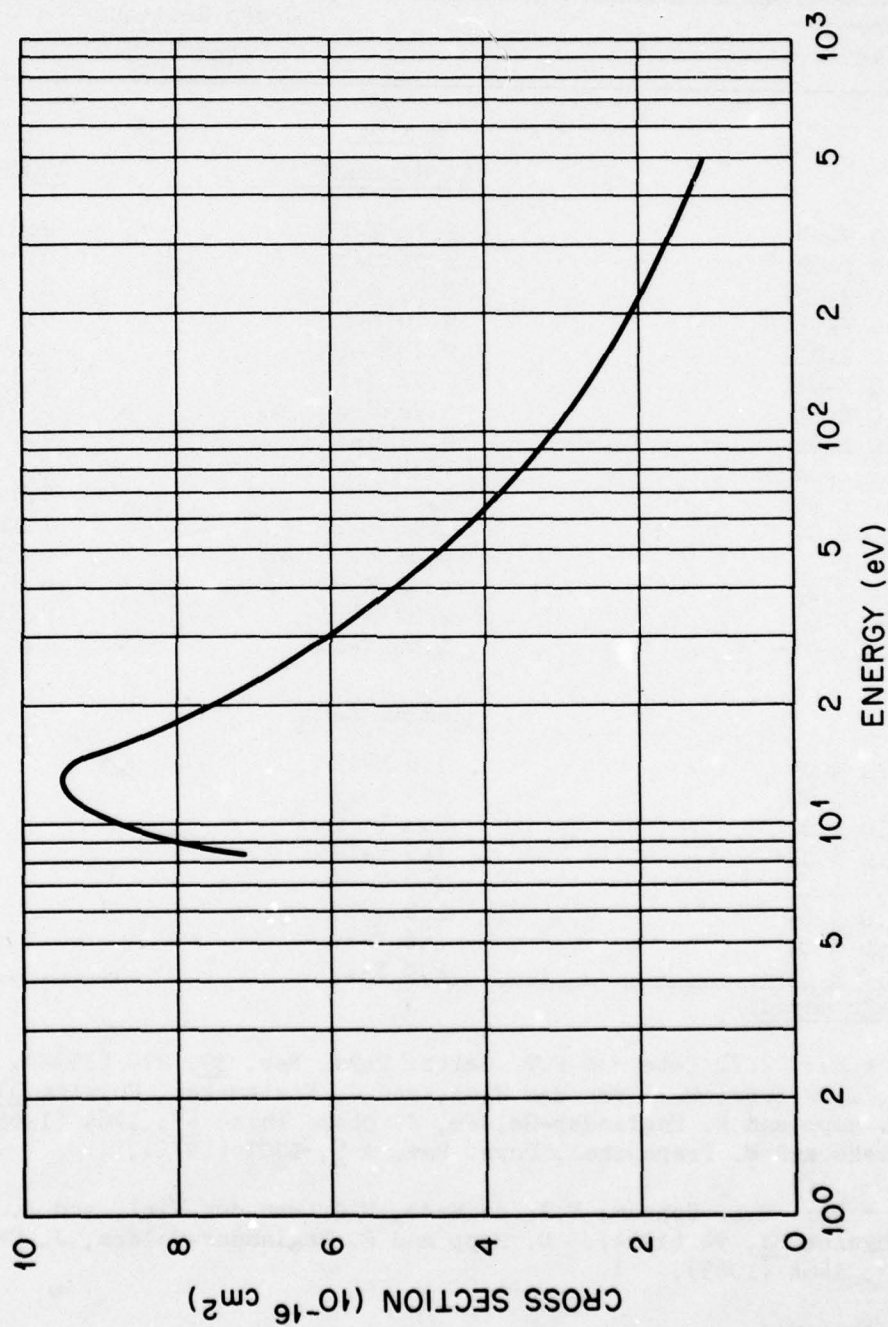
Reference:

A.J. Dixon, A. Von Engel, and M.F.A. Harrison, Proc. Roy. Soc. A-343,
333 (1975).

Accuracy:

The total error is believed not to exceed $\pm 25\%$.

Electron Impact Ionization Cross Section of Atomic Hydrogen
in the Metastable 2s State



Graphical Data C-4.4.

Tabular Data C-4.5.
Total Cross Sections σ_T for Ionization of Hydrogen
and Deuterium Molecules by Electron Impact

Energy (keV)	Cross Sections (cm ²)	
	<u>e + H₂</u>	<u>e + D₂</u>
	<u>Experimental</u>	<u>Experimental</u>
2.0 E-02	2.70 E-17	2.80 E-17
3.0 E-02	6.91 E-17	6.65 E-17
4.0 E-02	8.59 E-17	8.59 E-17
8.0 E-02	9.70 E-17	9.75 E-17
1.0 E-01	9.23 E-17	9.34 E-17
2.0 E-01	7.21 E-17	7.25 E-17
3.0 E-01	5.72 E-17	5.80 E-17
4.0 E-01	4.71 E-17	4.90 E-17
8.0 E-01	2.74 E-17	3.00 E-17
1.0 E 00	2.24 E-17	2.50 E-17
2.0 E 00	1.18 E-17	1.35 E-17
4.0 E 00	6.26 E-18	6.95 E-18
6.0 E 00	4.32 E-18	4.20 E-18
1.0 E 01	2.82 E-18	2.35 E-18
2.0 E 01	1.60 E-18	1.20 E-18
	<u>Theoretical</u>	
5.0 E 01	7.6 E-19	
1.0 E 02	4.6 E-19	
5.0 E 02	2.1 E-19	
1.0 E 03	1.9 E-19	
5.0 E 03	2.0 E-19	
1.0 E 04	2.2 E-19	
5.0 E 04	2.6 E-19	
1.0 E 05	2.8 E-19	

References:

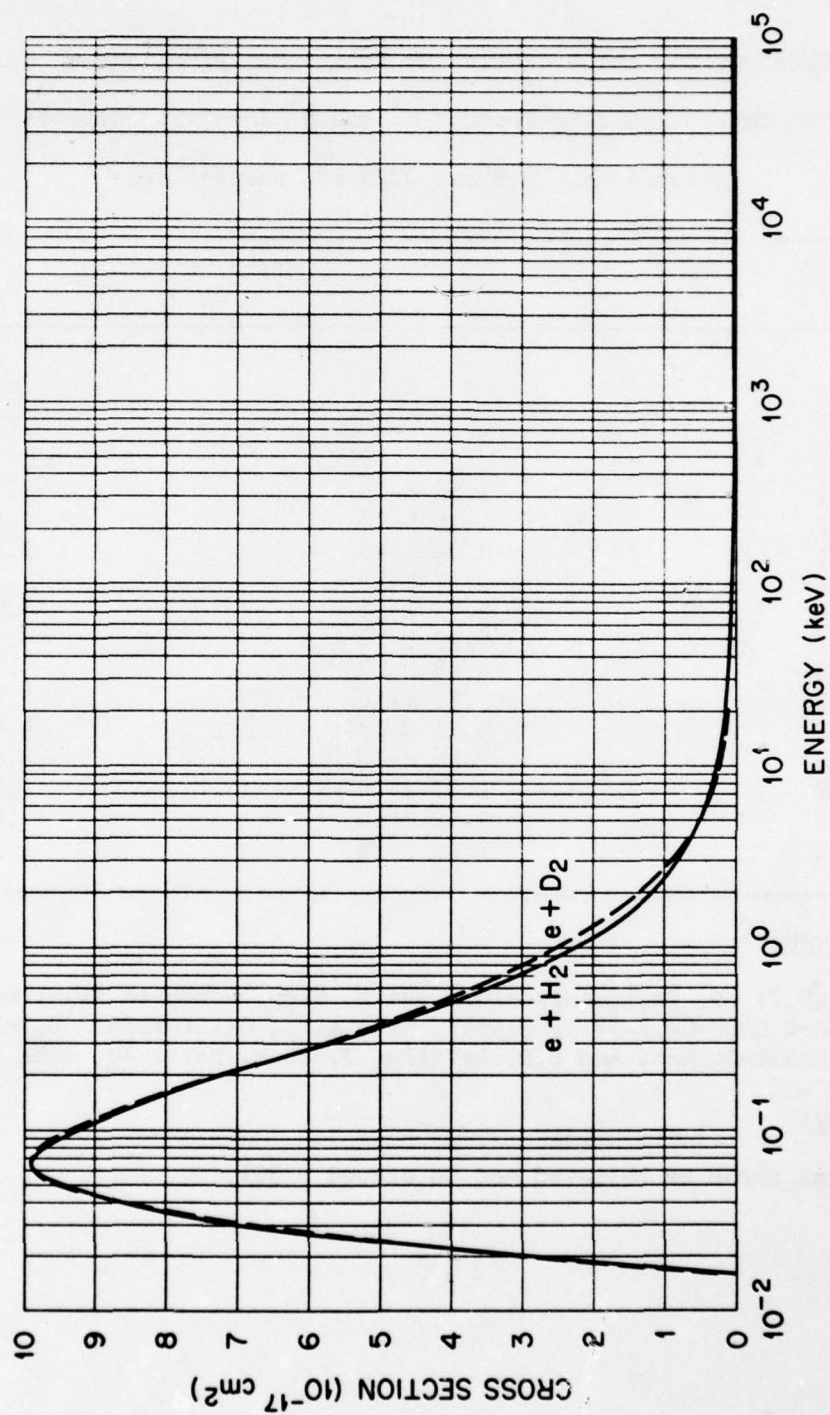
e + H₂: J.T. Tate and P.T. Smith, Phys. Rev. 39, 270 (1932). B.L. Schram, F.J. de Heer, M.J. van der Wiel, and J. Kistemaker, Physica 31, 94 (1964). D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965). F.F. Rieke and W. Prepejchal, Phys. Rev. A 6, 1507 (1972).

e + D₂: B.L. Schram, F.J. de Heer, M.J. van der Wiel, and J. Kistemaker, Physica 31, 94 (1964). D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965).

Accuracy:

The total error is believed not to exceed ± 12% for H₂ and D₂.

Total Cross Sections σ_T for Ionization of Hydrogen
and Deuterium Molecules by Electron Impact



Graphical Data C-4.6.

Tabular Data C-4.7.

Cross Sections for the Dissociative Ionization of H_2 and N_2 Molecules
by Electron Impact Yielding Product H^+ and N^+ Ions with Kinetic Energies
Greater than 2.5 and 0.25 eV, Respectively

Energy (eV)	Cross Section (cm^2)	
	<u>$e + H_2$</u>	<u>$e + N_2$</u>
2.5 E 01		
3.0 E 01	1.52 E-19	2.30 E-18
4.0 E 01	1.35 E-18	1.30 E-17
6.0 E 01	4.02 E-18	3.81 E-17
8.0 E 01	5.37 E-18	5.30 E-17
1.0 E 02	5.75 E-18	5.95 E-17
1.5 E 02	5.32 E-18	6.12 E-17
2.0 E 02	4.48 E-18	5.50 E-17
2.5 E 02	3.75 E-18	4.97 E-17
3.0 E 02	3.21 E-18	4.45 E-17
4.0 E 02	2.46 E-18	3.63 E-17
6.0 E 02	1.57 E-18	2.71 E-17
8.0 E 02	1.12 E-18	2.20 E-17
1.0 E 03	8.40 E-19	1.91 E-17

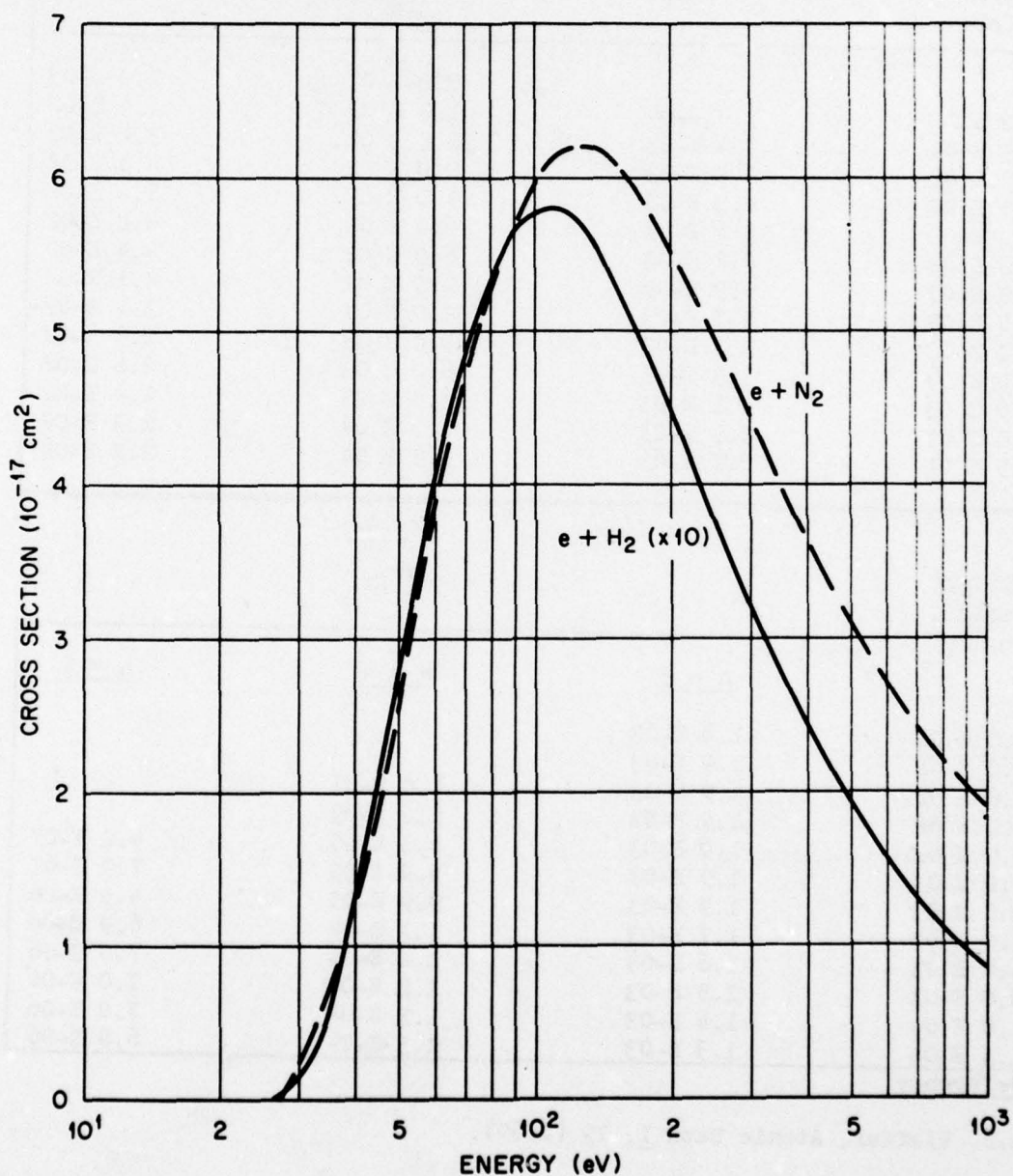
References:

$e + (H_2, N_2)$: P. Englander-Golden and D. Rapp, Lockheed Missiles and Space Co. Report LMSC-6-74-64-12 (1964), Palo Alto, California. D. Rapp, P. Englander-Golden, and D.D. Briglia, J. Chem. Phys. 42, 4081 (1965).

Accuracy:

The total error is believed not to exceed $\pm 30\%$.

Cross Sections for the Dissociative Ionization of H_2 and N_2 Molecules
by Electron Impact Yielding Product H^+ and N^+ Ions with Kinetic Energies
Greater than 2.5 and 0.25 eV, Respectively



Graphical Data C-4.8.

Tabular Data C-4.9.

Ratios of Cross Sections σ^{2+}/σ_T in Ionization of Atomic Helium
and σ^{n+}/σ_T in Ionization of Atomic Neon by Electron Impact

<u>e + He</u>		<u>e + Ne</u>	
Energy (eV)	σ^{2+}/σ_T	Energy (eV)	σ^{2+}/σ_T
1.0 E 02	7.0 E-04	8.0 E 01	7.0 E-03
1.5 E 02	2.4 E-03	1.0 E 02	1.4 E-02
2.0 E 02	3.8 E-03	1.5 E 02	3.2 E-02
4.0 E 02	6.3 E-03	2.0 E 02	4.5 E-02
6.0 E 02	6.6 E-03	4.0 E 02	5.4 E-02
8.0 E 02	6.2 E-03	6.0 E 02	4.8 E-02
1.0 E 03	5.9 E-03	8.0 E 02	4.4 E-02
2.0 E 03	4.7 E-03	1.0 E 03	4.1 E-02
4.0 E 03	3.7 E-03	2.0 E 03	3.4 E-02
6.0 E 03	3.3 E-03	4.0 E 03	2.8 E-02
8.0 E 03	3.1 E-03	6.0 E 03	2.6 E-02
1.0 E 04	2.9 E-03	8.0 E 03	2.4 E-02
1.5 E 04	2.7 E-03	1.0 E 04	2.3 E-02
		1.5 E 04	2.2 E-02

<u>e + Ne</u>			
Energy (eV)	σ^{n+}/σ_T		
	<u>n = 3</u>	<u>n = 4</u>	<u>n = 5</u>
3.0 E 02	1.8 E-03		
4.0 E 02	1.9 E-03		
5.0 E 02	1.9 E-03	4.0 E-05	
7.0 E 02	1.9 E-03	5.0 E-05	
8.0 E 02	1.9 E-03	5.3 E-05	4.0 E-07
1.0 E 03	1.9 E-03	5.9 E-05	7.9 E-07
2.0 E 03	1.9 E-03	9.9 E-05	4.5 E-06
4.0 E 03	1.7 E-03	1.1 E-04	6.9 E-06
6.0 E 03	1.6 E-03	1.2 E-04	7.0 E-06
8.0 E 03	1.5 E-03	1.2 E-04	7.0 E-06
1.0 E 04	1.4 E-03	1.3 E-04	7.0 E-06
1.5 E 04	1.3 E-03	1.3 E-04	6.8 E-06

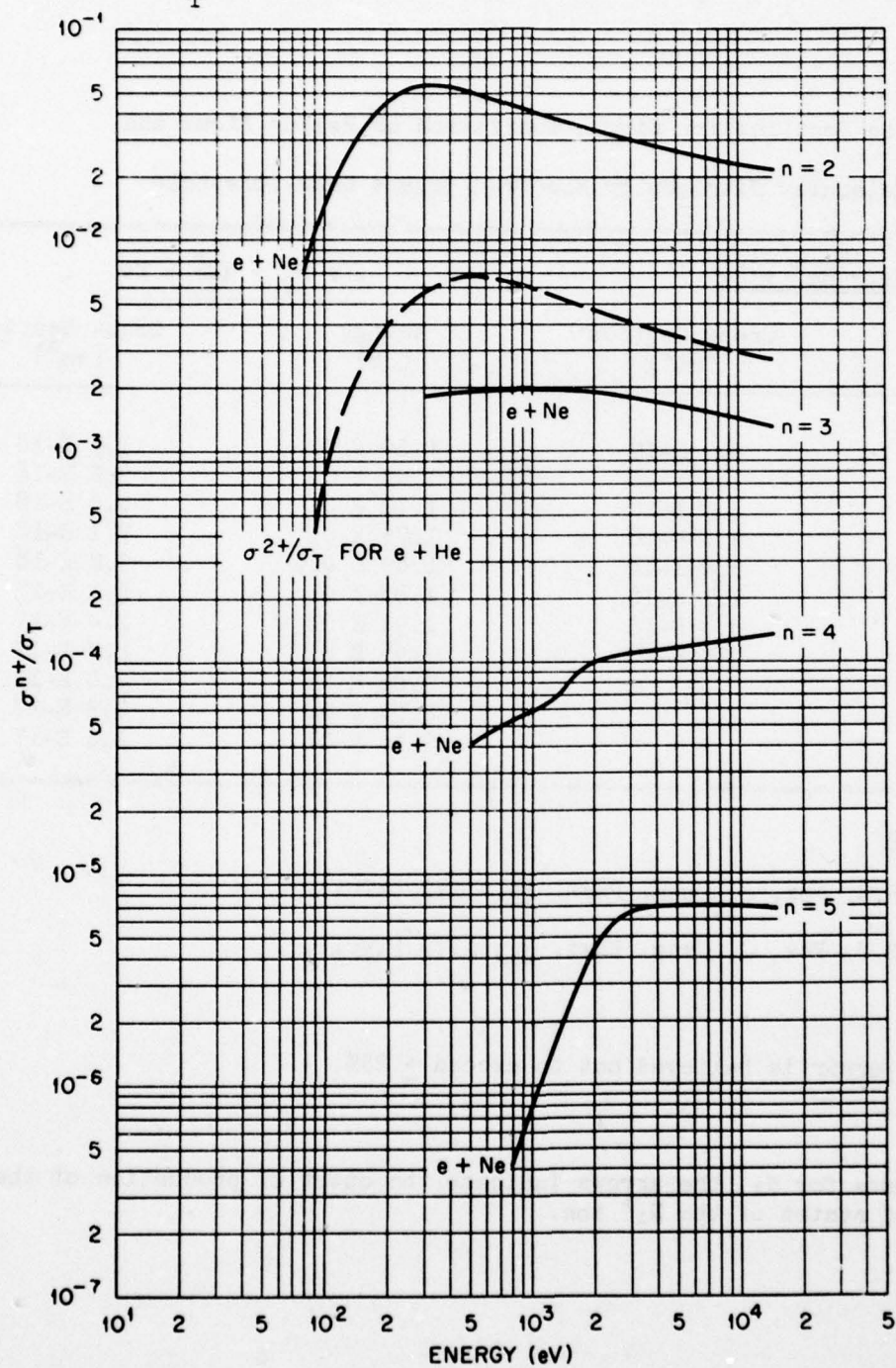
Reference:

L.J. Kieffer, Atomic Data 1, 19 (1969).

Accuracy:

The total error is believed not to exceed + 20%.

Ratios of Cross Sections σ^{2+}/σ_T in Ionization of Atomic Helium
and σ^{n+}/σ_T in Ionization of Atomic Neon by Electron Impact



Graphical Data C-4.10.

Tabular Data C-4.11.

Cross Sections for Single Ionization of Helium Atoms and
Molecular Nitrogen by Electron Impact Near Threshold

<u>$e + \text{He} \rightarrow \text{He}^+ + 2e$</u>		<u>$e + \text{N}_2 \rightarrow \text{N}_2^+ + 2e$</u>	
Energy (eV)	Cross Section (cm^2)	Energy (eV)	Cross Section (cm^2)
2.5 E 01	6.0 E-19	1.60 E 01	1.5 E-18
2.6 E 01	1.9 E-18	1.65 E 01	3.2 E-18
2.7 E 01	3.2 E-18	1.70 E 01	5.0 E-18
2.8 E 01	4.5 E-18	1.75 E 01	7.1 E-18
2.9 E 01	5.8 E-18	1.80 E 01	9.2 E-18
3.0 E 01	7.1 E-18	1.85 E 01	1.1 E-17
3.1 E 01	8.4 E-18	1.90 E 01	1.4 E-17
3.2 E 01	9.7 E-18	1.95 E 01	1.7 E-17
		2.00 E 01	2.0 E-17
		2.05 E 01	2.3 E-17
		2.10 E 01	2.6 E-17

References:

$e + \text{He}$: R.E. Fox, J. Chem. Phys. 35, 1379 (1961).

$e + \text{N}_2$: R.E. Fox, J. Chem. Phys. 35, 1379 (1961).

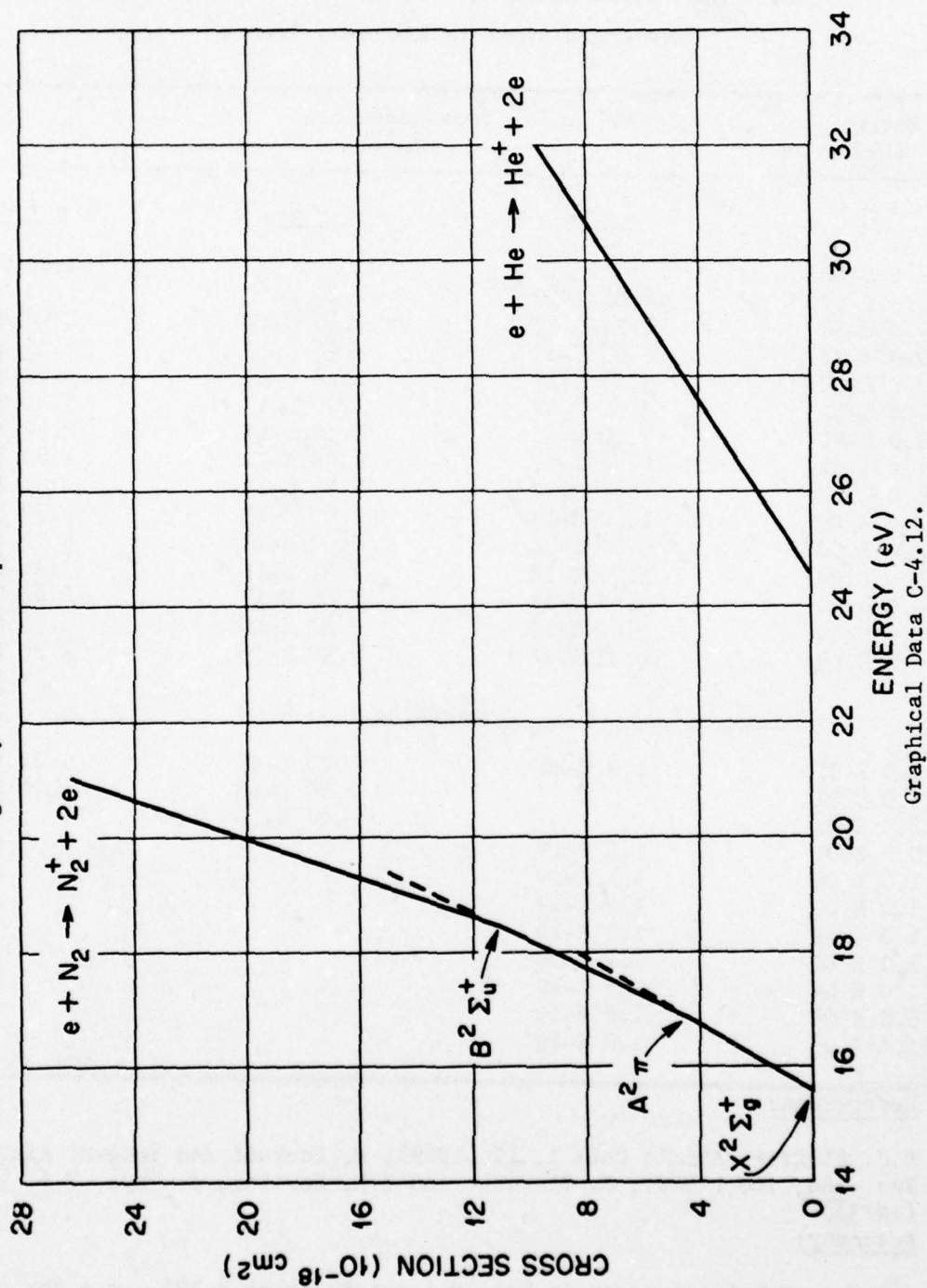
Accuracy:

The total error is believed not to exceed $\pm 25\%$.

Note:

On the curve for N_2 , the arrows indicate the onset of production of the designated states of the N_2^+ ion.

Cross sections for single ionization of helium atoms and molecular nitrogen by electron impact near threshold



Graphical Data C-4.12.

Tabular Data C-4.13.
Total Cross Sections σ_T for Ionization of Helium, Neon,
and Argon Atoms by Electron Impact

Energy (keV)	Cross Sections (cm ²)		
	<u>e + He</u>	<u>e + Ne</u>	<u>e + Ar</u>
2.0 E-02			7.40 E-17
2.5 E-02	8.80 E-19	4.10 E-18	1.50 E-16
4.0 E-02	1.71 E-17	2.30 E-17	2.48 E-16
6.0 E-02	2.99 E-17	4.65 E-17	2.85 E-16
8.0 E-02	3.41 E-17	6.12 E-17	3.00 E-16
1.0 E-01	3.60 E-17	7.00 E-17	3.01 E-16
2.0 E-01	3.38 E-17	8.10 E-17	2.50 E-16
4.0 E-01	2.44 E-17	6.48 E-17	1.80 E-16
8.0 E-01	1.48 E-17	4.27 E-17	1.01 E-16
1.0 E 00	1.22 E-17	3.60 E-17	8.50 E-17
2.0 E 00	6.92 E-18	2.00 E-17	4.70 E-17
3.0 E 00	5.20 E-18	1.41 E-17	3.38 E-17
4.0 E 00	4.19 E-18	1.08 E-17	2.68 E-17
6.0 E 00	3.00 E-18	7.80 E-18	1.98 E-17
8.0 E 00	2.31 E-18	5.90 E-18	1.58 E-17
<hr/> Theoretical <hr/>			
1.0 E 01	1.9 E-18	5.20 E-18	1.20 E-17
1.5 E 01		3.60 E-18	8.20 E-18
2.0 E 01		2.70 E-18	
5.0 E 01	5.1 E-19		
1.0 E 02	3.1 E-19		
5.0 E 02	1.4 E-19		
1.0 E 03	1.3 E-19		
5.0 E 03	1.4 E-19		
1.0 E 04	1.5 E-19		
5.0 E 04	1.8 E-19		
1.0 E 05	1.9 E-19		

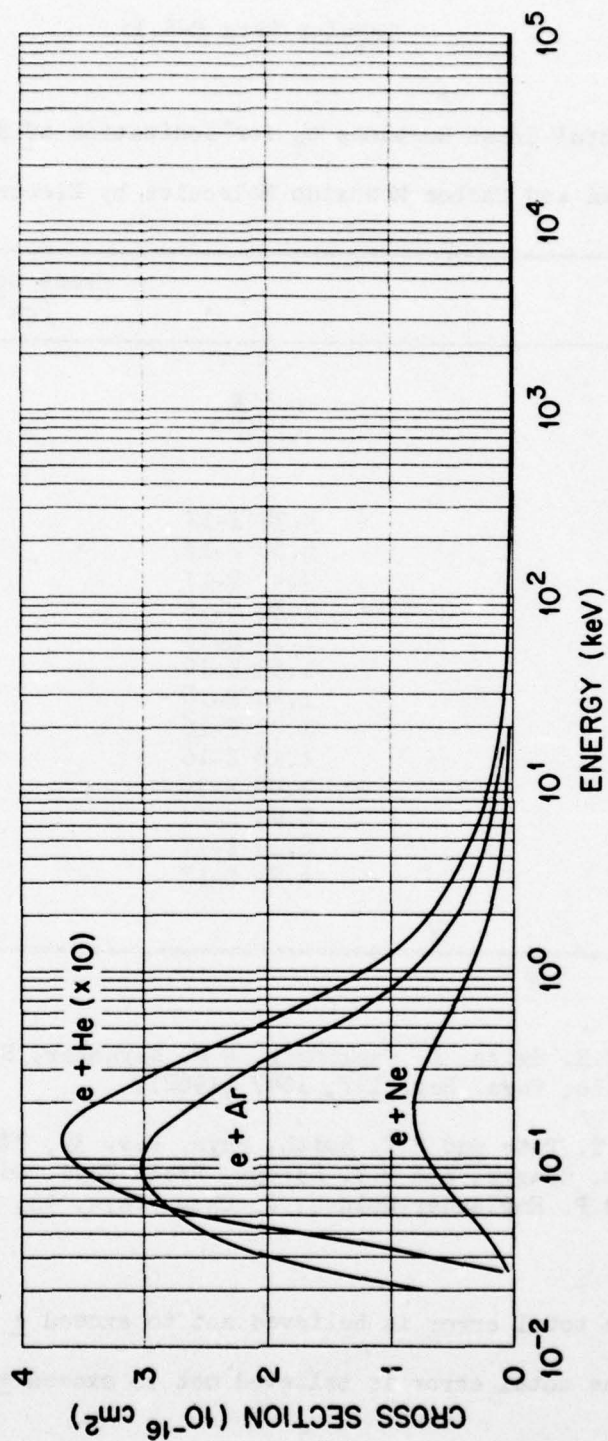
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L.J. Kieffer, Atomic Data 1, 19 (1969); M. Inokuti and Yong-Ki Kim, Phys. Rev. 186, 100 (1969); J. Fletcher and I.R. Cowling, J. Phys. B 6, L-258 (1973).

Accuracy:

e + He: The total error is believed not to exceed $\pm 12\%$. e + Ne: The total error is believed not to exceed $\pm 15\%$. e + Ar: The total error is believed not to exceed $\pm 25\%$.

Total Cross Sections σ_T for Ionization of Helium, Neon,
and Argon Atoms by Electron Impact



Graphical Data C-4.14.

Tabular Data C-4.15.

Total Cross Sections σ_T for Ionization of Nitrogen
Atoms and Carbon Monoxide Molecules by Electron Impact

Energy (eV)	Cross Sections (cm ²)	
	<u>e + N</u>	<u>e + CO</u>
2.0 E 01		4.29 E-17
2.5 E 01	4.79 E-17	8.79 E-17
3.0 E 01	6.50 E-17	1.27 E-16
4.0 E 01	9.40 E-17	1.83 E-16
6.0 E 01	1.36 E-16	2.47 E-16
8.0 E 01	1.50 E-16	2.81 E-16
1.0 E 02	1.53 E-16	2.89 E-16
1.5 E 02	1.40 E-16	2.72 E-16
2.0 E 02	1.30 E-16	2.49 E-16
2.5 E 02	1.18 E-16	2.26 E-16
3.0 E 02	1.08 E-16	2.05 E-16
4.0 E 02	8.93 E-17	1.72 E-16
6.0 E 02	6.10 E-17	1.33 E-16
8.0 E 02	4.21 E-17	1.10 E-16
1.0 E 03		9.40 E-17

References:

e + N: A.C.H. Smith, E. Caplinger, R.H. Neynaber, E.W. Rothe, and S.M. Trujillo, Phys. Rev. 127, 1647 (1962).

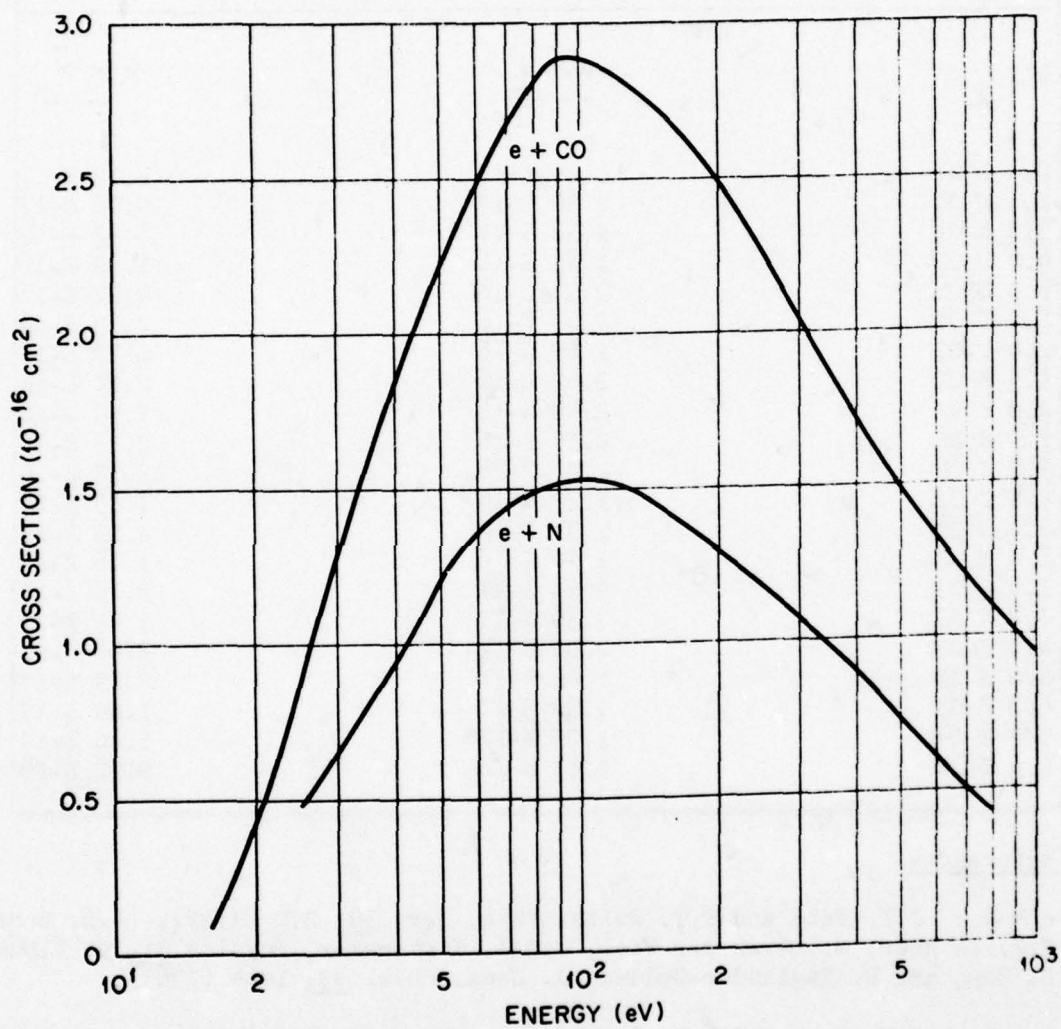
e + CO: J.T. Tate and P.T. Smith, Phys. Rev. 39, 270 (1932). R.K. Asundi, J.D. Craggs, and M.V. Kurepa, Proc. Phys. Soc. 82, 967 (1963). D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965).

Accuracy:

e + N: The total error is believed not to exceed ± 30%.

e + CO: The total error is believed not to exceed ± 18%.

Total Cross Sections σ_T for Ionization of Nitrogen
Atoms and Carbon Monoxide Molecules by Electron Impact



Graphical Data C-4.16.

Tabular Data C-4.17.

Total Cross Sections σ_T for Ionization of
Nitrogen and Oxygen Molecules by Electron Impact

Energy (eV)	Cross Sections (cm ²)	
	<u>e + N₂</u>	<u>e + O₂</u>
2.0 E 01	3.19 E-17	3.12 E-17
2.5 E 01	6.36 E-17	5.92 E-17
3.0 E 01	9.38 E-17	8.82 E-17
4.0 E 01	1.55 E-16	1.50 E-16
6.0 E 01	2.34 E-16	2.32 E-16
8.0 E 01	2.61 E-16	2.62 E-16
1.0 E 02	2.69 E-16	2.77 E-16
1.5 E 02	2.62 E-16	2.74 E-16
2.0 E 02	2.40 E-16	2.59 E-16
2.5 E 02	2.19 E-16	2.38 E-16
3.0 E 02	2.01 E-16	2.17 E-16
4.0 E 02	1.72 E-16	1.85 E-16
6.0 E 02	1.34 E-16	1.42 E-16
8.0 E 02	1.10 E-16	1.16 E-16
1.0 E 03	9.36 E-17	9.76 E-17
2.0 E 03	5.30 E-17	5.42 E-17
4.0 E 03	2.92 E-17	3.00 E-17
6.0 E 03	1.96 E-17	2.19 E-17
8.0 E 03	1.50 E-17	1.69 E-17
1.0 E 04	1.23 E-17	1.40 E-17
1.5 E 04	8.80 E-18	9.92 E-18

References:

e + N₂: J.T. Tate and P.T. Smith, Phys. Rev. 39, 270 (1932). B.L. Schram, F.J. de Heer, M.J. van der Wiel, and J. Kistemaker, Physica 31, 94 (1964). D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965).

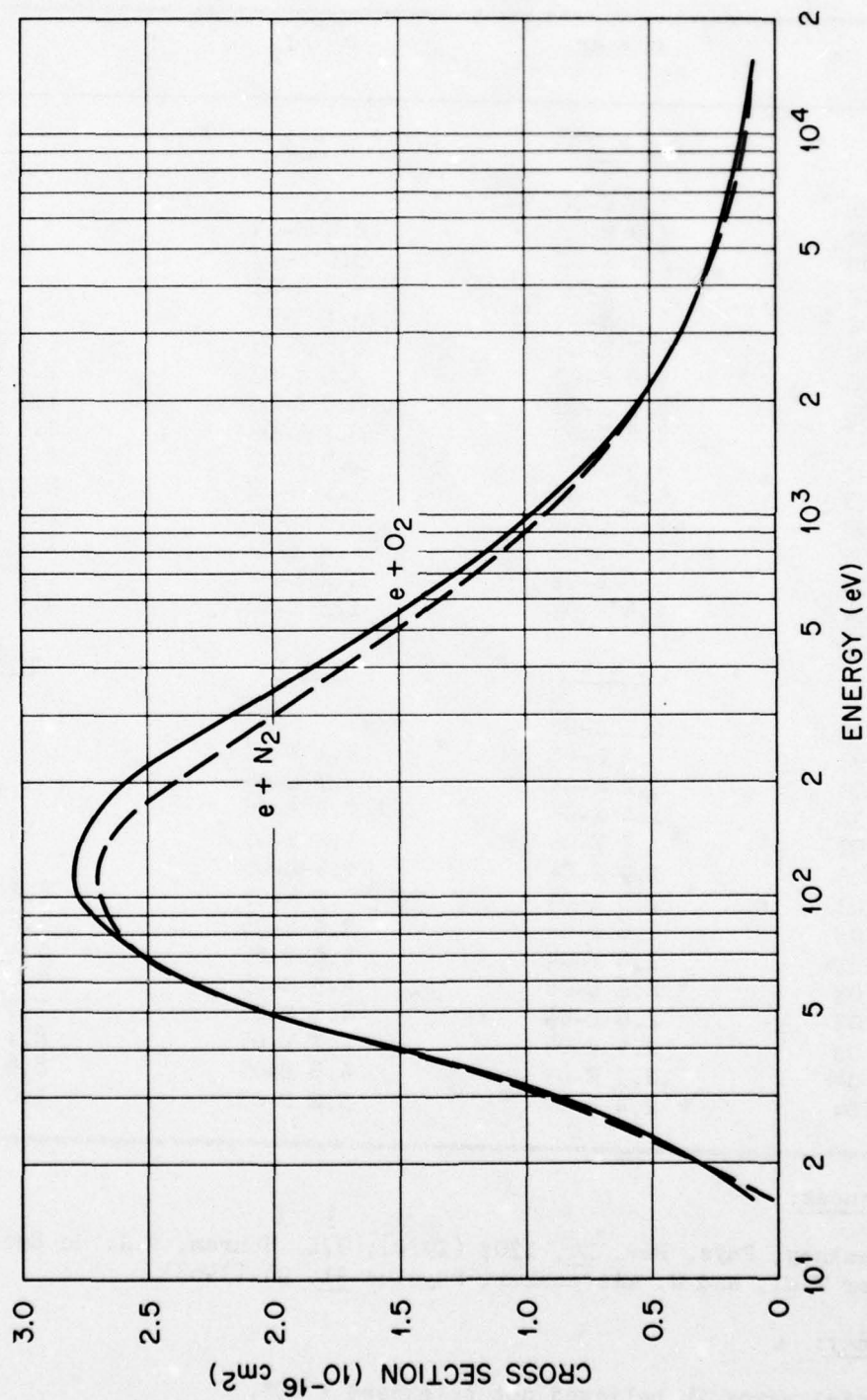
e + O₂: J.T. Tate and P.T. Smith, Phys. Rev. 39, 270 (1932). R.K. Asundi, J.D. Craggs, and M.V. Kurepa, Proc. Phys. Soc. 82, 967 (1963). B.L. Schram, F.J. de Heer, M.J. van der Wiel, and J. Kistemaker, Physica 31, 94 (1964). D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965).

Accuracy:

The total error is believed not to exceed $\pm 15\%$ for e + N₂.

The total error is believed not to exceed $\pm 15\%$ for e + O₂.

Total Cross Sections σ_T for Ionization of
Nitrogen and Oxygen Molecules by Electron Impact



Graphical Data C-4.18.

Tabular Data C-4.19.

ios of Cross Sections σ^{n+}/σ_T in Ionization of Atomic Argon by Electron Imp

Energy (eV)	e + Ar	σ^{n+}/σ_T		
		<u>n = 2</u>	<u>n = 3</u>	<u>n = 4</u>
8.0 E 01	7.6 E-02			
1.0 E 02	7.9 E-02		2.0 E-03	
2.0 E 02	8.0 E-02		3.6 E-03	
3.0 E 02	7.1 E-02		4.8 E-03	
4.0 E 02	6.4 E-02		5.7 E-03	4.0 E-04
5.0 E 02	5.7 E-02		6.5 E-03	7.9 E-04
7.0 E 02	5.0 E-02		7.6 E-03	1.2 E-03
8.0 E 02	4.9 E-02		8.0 E-03	1.3 E-03
1.0 E 03	4.8 E-02		8.7 E-03	1.5 E-03
2.0 E 03	4.6 E-02		1.0 E-02	2.0 E-03
4.0 E 03	4.6 E-02		1.1 E-02	2.0 E-03
6.0 E 03	4.6 E-02		1.2 E-02	2.0 E-03
8.0 E 03	4.6 E-02		1.2 E-02	2.0 E-03
1.0 E 04	4.6 E-02		1.2 E-02	2.0 E-03
1.5 E 04	4.6 E-02		1.3 E-02	2.0 E-03
		<u>n = 5</u>	<u>n = 6</u>	<u>n = 7</u>
5.0 E 02	6.1 E-05			
6.0 E 02	8.8 E-05		2.1 E-06	
7.0 E 02	1.2 E-04		4.7 E-06	
8.0 E 02	1.4 E-04		7.8 E-06	
9.0 E 02	1.7 E-04		1.2 E-05	
1.0 E 03	1.9 E-04		1.5 E-05	
1.5 E 03	2.5 E-04		2.9 E-05	2.2 E-06
2.0 E 03	2.6 E-04		3.4 E-05	3.2 E-06
4.0 E 03	2.6 E-04		4.0 E-05	5.4 E-06
6.0 E 03	2.6 E-04		4.3 E-05	6.7 E-06
8.0 E 03	2.6 E-04		4.6 E-05	7.7 E-06
9.0 E 03	2.5 E-04		4.7 E-05	8.1 E-06
1.0 E 04	2.5 E-04		4.8 E-05	8.6 E-06
1.5 E 04	2.4 E-04		5.2 E-05	1.0 E-05

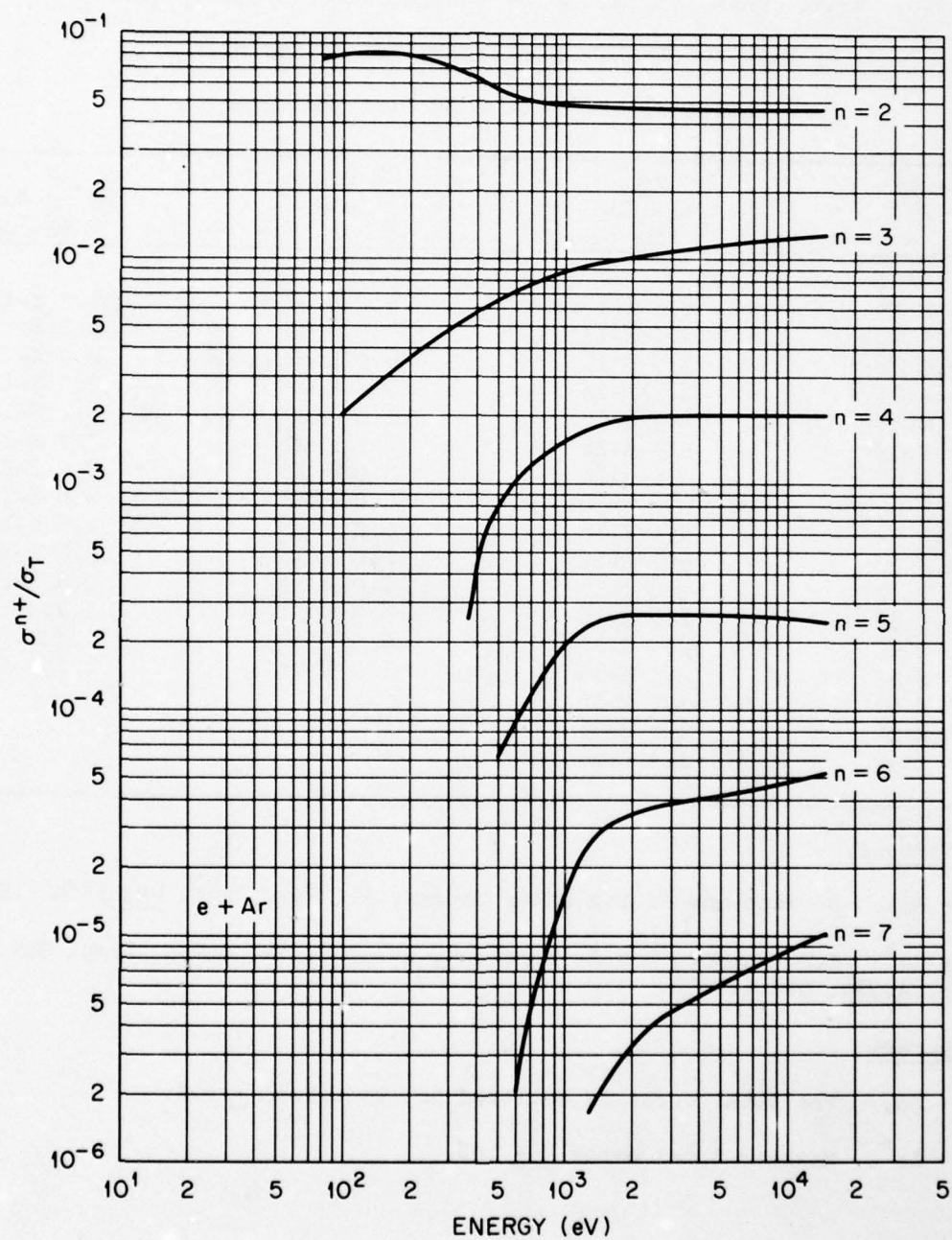
References:

W. Bleakney, Phys. Rev. 36, 1303 (1930); B.L. Schram, F.J. de Heer, M.J. Van der Wiel, and J. Kistemaker, Physica 31, 94 (1965).

Accuracy:

The total error is believed not to exceed + 20%.

Ratios of Cross Sections σ^{n+}/σ_T in Ionization of Atomic Argon by Electron Impact



Graphical Data C-4.20.

Tabular Data C-4.21.

Total Cross Section σ_T for Ionization of Carbon Dioxide
by Electron Impact, and Cross Section for Single
Ionization of Ne^+ Ions by Electron Impact

Energy (eV)	σ_T e + CO ₂ (cm ²)	Energy (eV)	σ e+Ne ⁺ → Ne ²⁺ +2e (cm ²)
1.5 E 01	8.6 E-18	5.0 E 01	4.3 E-18
2.0 E 01	5.0 E-17	7.5 E 01	1.5 E-17
3.0 E 01	1.5 E-16	1.0 E 02	2.4 E-17
4.0 E 01	2.2 E-16	1.5 E 02	3.0 E-17
6.0 E 01	2.9 E-16	2.0 E 02	3.1 E-17
8.0 E 01	3.4 E-16	2.5 E 02	3.0 E-17
1.0 E 02	3.5 E-16	3.0 E 02	2.9 E-17
1.4 E 02	3.5 E-16	4.0 E 02	2.6 E-17
1.8 E 02	3.4 E-16	5.0 E 02	2.3 E-17
2.2 E 02	3.1 E-16	6.0 E 02	2.2 E-17
2.6 E 02	3.0 E-16	7.0 E 02	2.0 E-17
3.0 E 02	2.8 E-16	8.0 E 02	1.9 E-17
4.0 E 02	2.4 E-16	9.0 E 02	1.8 E-17
5.0 E 02	2.1 E-16	1.0 E 03	1.6 E-17
6.0 E 02	1.9 E-16		
8.0 E 02	1.6 E-16		
1.0 E 03	1.4 E-16		

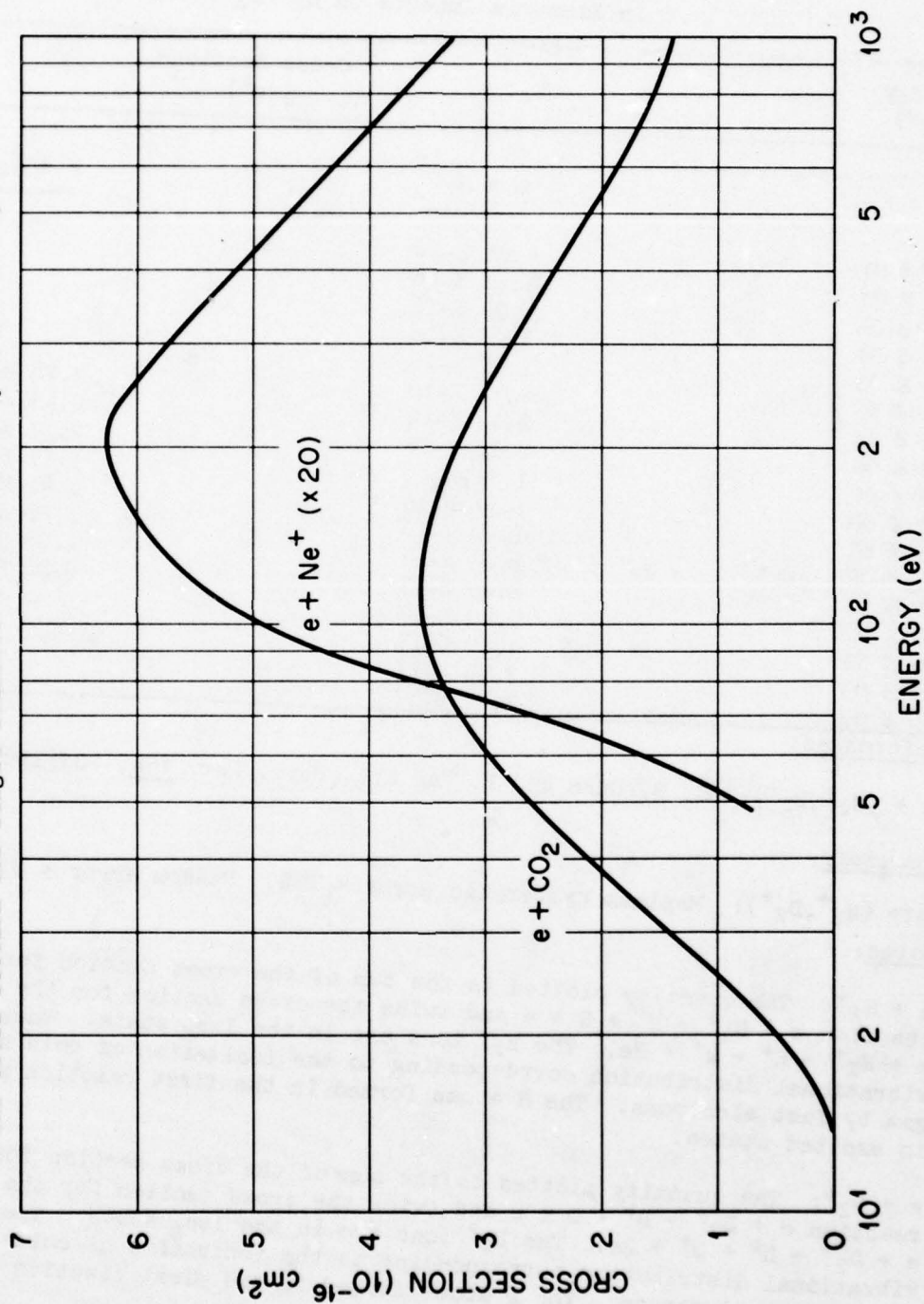
References:

e + CO₂: D. Rapp and P. Englander-Golden, J. Chem. Phys., 43, 1464 (1965).
e + Ne⁺: K.T. Dolder, M.F.A. Harrison, and P.C. Thonemann, Proc. Roy. Soc. A-274, 546 (1963).

Accuracy:

e + CO₂: The total error is believed not to exceed $\pm 30\%$.
e + Ne⁺: Maximum total error $\leq \pm 10\%$.

Total cross section σ_T for ionization of carbon dioxide by electron impact,
and cross section for single ionization of Ne^+ ions by electron impact.



Graphical Data. C-4.22.

Tabular Data C-4.23.
Cross Section for the Production of $H^+(D^+)$ Ions
in Electron Impacts on $H_2^+(D_2^+)$ Ions

Energy (eV)	Cross Sections (cm ²)	
	<u>$e + H_2^+$</u>	<u>$e + D_2^+$</u>
1.5 E 01	4.75 E-16	
2.0 E 01	4.31 E-16	
2.5 E 01	3.99 E-16	
3.0 E 01	3.72 E-16	
4.0 E 01	3.32 E-16	
6.0 E 01	2.78 E-16	2.78 E-16
8.0 E 01	2.43 E-16	2.43 E-16
1.0 E 02	2.17 E-16	2.17 E-16
1.5 E 02	1.71 E-16	1.71 E-16
2.0 E 02	1.41 E-16	1.41 E-16
2.5 E 02	1.20 E-16	1.20 E-16
3.0 E 02	1.03 E-16	1.03 E-16
4.0 E 02	8.00 E-17	8.00 E-17
6.0 E 02	5.40 E-17	
8.0 E 02	4.20 E-17	
1.0 E 03	3.50 E-17	
1.5 E 03	2.47 E-17	

References:

$e + (H_2^+, D_2^+)$: G. H. Dunn and B. Van Zyl, Phys. Rev. 154, 40 (1967).

Accuracy:

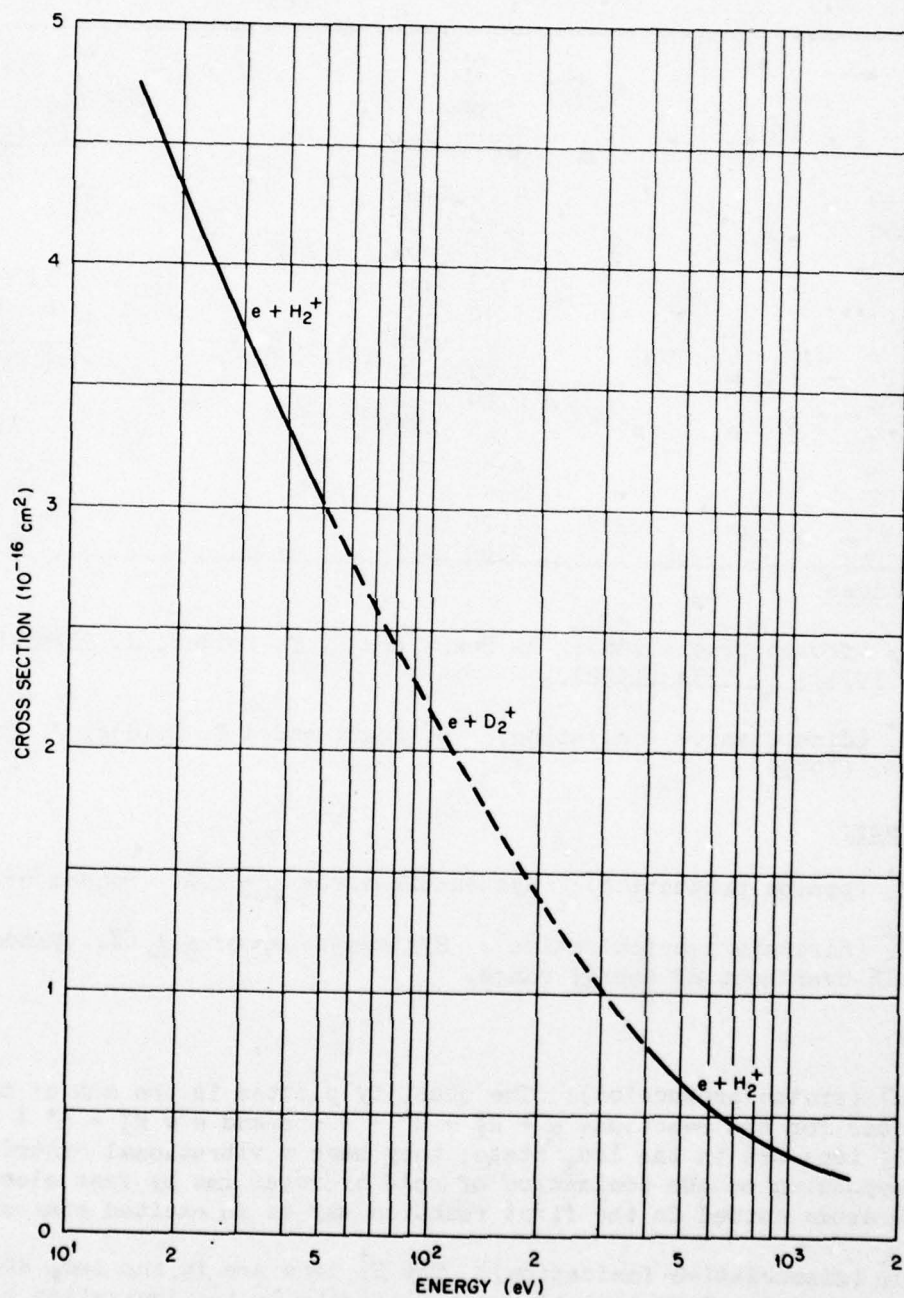
$e + (H_2^+, D_2^+)$: Maximum systematic error < 10%. Random error < 5%.

Notes:

$e + H_2^+$: The quantity plotted is the sum of the cross section for the reaction $e + H_2^+ \rightarrow H^+ + H + e$ and twice the cross section for the reaction $e + H_2^+ \rightarrow H^+ + H^+ + 2e$. The H_2^+ ions are in the $1s\sigma_g$ state. They have a vibrational distribution corresponding to the ionization of cold hydrogen gas by fast electrons. The H atoms formed in the first reaction may be in excited states.

$e + D_2^+$: The quantity plotted is the sum of the cross section for the reaction $e + D_2^+ \rightarrow D^+ + D + e$ and twice the cross section for the reaction $e + D_2^+ \rightarrow D^+ + D^+ + 2e$. The D_2^+ ions are in the $1s\sigma_g$ state. They have a vibrational distribution corresponding to the ionization of cold deuterium gas by fast electrons. The D atoms formed in the first reaction may be in excited states.

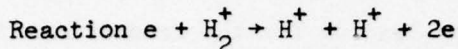
Cross Section for the Production of $H^+(D^+)$ Ions
in Electron Impacts on $H_2^+(D_2^+)$ Ions



Graphical Data C-4.24.

Tabular Data C-4.25

Cross Section for the Production of Protons in Electron Impacts
on H_2^+ Ions and Cross Section for the Dissociative Ionization



Energy (eV)	Cross Section (cm^2)	
	$e + H_2^+$ Proton Production	$e + H_2^+$ Dissociative Ionization
4.0 E 00	9.90 E-16	
8.0 E 00	7.98 E-16	
1.0 E 01	6.87 E-16	
2.0 E 01	4.73 E-16	1.06 E-18
4.0 E 01	3.46 E-16	6.90 E-18
6.0 E 01	2.81 E-16	1.30 E-17
8.0 E 01	2.40 E-16	1.62 E-17
1.0 E 02	2.09 E-16	1.75 E-17
2.0 E 02	1.24 E-16	1.33 E-17
3.0 E 02	9.20 E-17	9.71 E-18
4.0 E 02	7.50 E-17	7.60 E-18
8.0 E 02	4.20 E-17	4.57 E-18
1.0 E 03	3.40 E-17	4.00 E-18

References:

$e + H_2^+$ (proton production): B. Peart and K. T. Dolder, J. Phys. B 4, 1496 (1971); 5, 1554 (1972).

$e + H_2^+$ (dissociative ionization): B. Peart and K.T. Dolder, J. Phys. B 6, 2409 (1973).

Accuracy:

$e + H_2^+$ (proton production): Systematic error $\leq \pm 10\%$. Random error $\pm 10\%$.

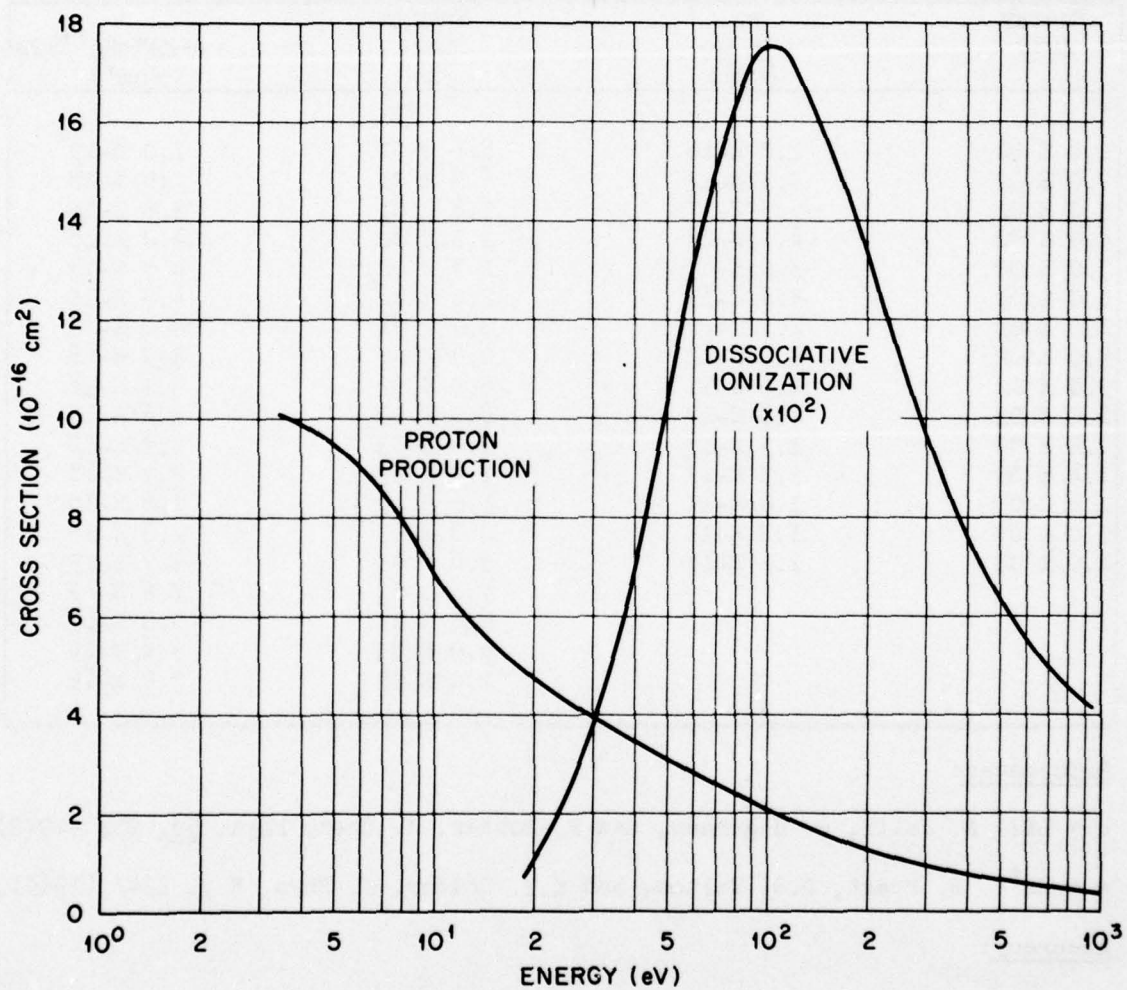
$e + H_2^+$ (dissociative ionization): Systematic error $< \pm 6\%$. Random error $\leq \pm 11\%$ over most of energy range.

Notes:

$e + H_2^+$ (proton production): The quantity plotted is the sum of the cross sections for the reactions $e + H_2^+ \rightarrow H^+ + H + e$ and $e + H_2^+ \rightarrow H^+ + H^+ + 2e$. The H_2^+ ions are in the $1s\sigma_g$ state; they have a vibrational distribution corresponding to the ionization of cold hydrogen gas by fast electrons. The H atoms formed in the first reaction may be in excited states.

$e + H_2^+$ (dissociative ionization): The H_2^+ ions are in the $1s\sigma_g$ state; they have a vibrational distribution corresponding to the ionization of cold hydrogen gas by fast electrons.

Cross Section for the Production of Protons in Electron Impacts
 on H_2^+ Ions and Cross Section for the Dissociative Ionization
 Reaction $e + \text{H}_2^+ \rightarrow \text{H}^+ + \text{H}^+ + 2e$



Graphical Data C-4.26

Tabular Data C-4.27

Total Cross Section, σ_T , for Ionization of Atomic Lithium by Electron Impact, and Cross Section for Production of He^{2+} from He^+ by Electron Impact

Energy (eV)	σ_T e + Li (cm ²)	Energy (eV)	σ e+He ⁺ →He ²⁺ +2e (cm ²)
1.0 E 02	1.0 E-16	5.5 E 01	1.0 E-19
2.0 E 02	7.4 E-17	6.8 E 01	1.5 E-18
3.0 E 02	5.5 E-17	9.8 E 01	3.6 E-18
4.0 E 02	4.5 E-17	1.2 E 02	4.0 E-18
5.0 E 02	3.6 E-17	1.7 E 02	4.8 E-18
6.0 E 02	3.0 E-17	2.0 E 02	4.5 E-18
7.0 E 02	2.5 E-17	3.0 E 02	4.2 E-18
8.0 E 02	2.2 E-17	4.0 E 02	3.9 E-18
9.0 E 02	2.0 E-17	6.0 E 02	3.1 E-18
1.0 E 03	1.8 E-17	8.0 E 02	2.6 E-18
1.2 E 03	1.5 E-17	1.0 E 03	2.2 E-18
1.4 E 03	1.3 E-17	1.2 E 03	2.1 E-18
1.6 E 03	1.2 E-17	1.6 E 03	1.6 E-18
1.8 E 03	1.2 E-17	2.0 E 03	1.3 E-18
2.0 E 03	1.1 E-17	3.0 E 03	9.7 E-19
		4.0 E 03	7.6 E-19
		6.0 E 03	5.0 E-19
		8.0 E 03	3.9 E-19
		1.0 E 04	3.2 E-19

References:

e + Li: R. Jalin, R. Hagemann, and R. Botter, J. Chem. Phys. 59, 952 (1973).

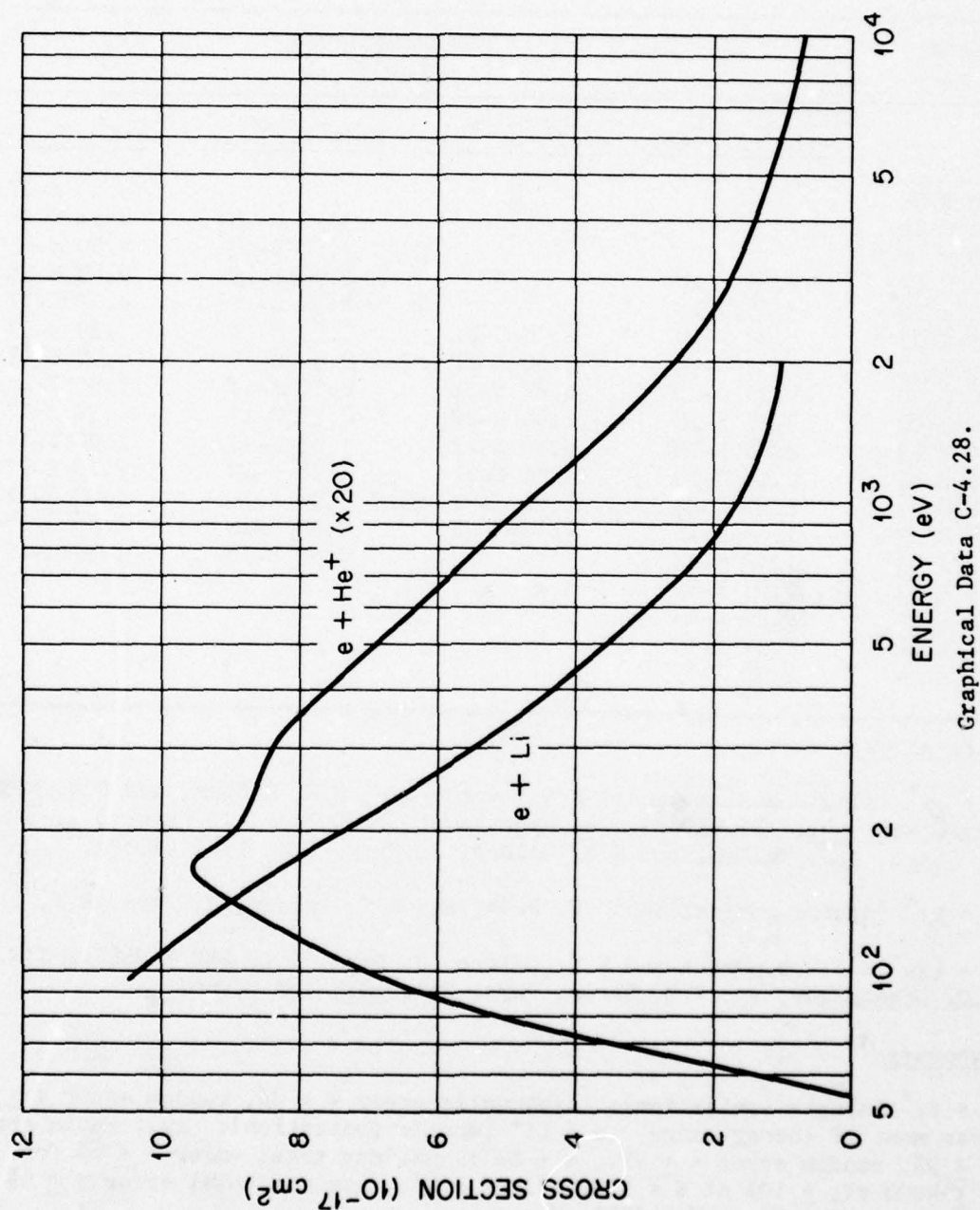
e + He⁺: B. Peart, D.S. Walton, and K.T. Dolder, J. Phys. B 2, 1347 (1969).

Accuracy:

e + Li: The total error is believed not to exceed $\pm 15\%$.

e + He⁺: Systematic error < 8%. Random error < 9% over most of the energy range.

Total Cross Section, σ_T , for Ionization of Atomic Lithium by Electron Impact, and Cross Section for Production of He^{2+} from He^+ by Electron Impact



Graphical Data C-4.28.

Tabular Data C-4.29.

Cross Sections for Single and Double Ionization of Li^+ Ions and
Cross Sections for Single Ionization of Na^+ and K^+ Ions by Electron Impact

Energy (eV)	Cross Sections (cm^2)			
	$e + \text{Li}^+ \rightarrow \text{Li}^{2+} + 2e$	$e + \text{Li}^+ \rightarrow \text{Li}^{3+} + 3e$	$e + \text{Na}^+ \rightarrow \text{Na}^{2+} + 2e$	$e + \text{K}^+ \rightarrow \text{K}^{2+} + 2e$
4.0 E 01				3.80 E-17
6.0 E 01			3.30 E-18	8.54 E-17
8.0 E 01			9.10 E-18	9.80 E-17
1.0 E 02	1.52 E-18		1.50 E-17	9.83 E-17
1.5 E 02	3.45 E-18		2.32 E-17	9.17 E-17
2.5 E 02	4.08 E-18	2.04 E-21	2.67 E-17	7.39 E-17
3.0 E 02	4.13 E-18	3.80 E-21	2.64 E-17	6.55 E-17
4.0 E 02	4.09 E-18	6.82 E-21	2.50 E-17	5.55 E-17
6.0 E 02	3.71 E-18	1.00 E-20	2.18 E-17	4.30 E-17
1.0 E 03	2.85 E-18	9.56 E-21	1.68 E-17	3.00 E-17
1.5 E 03	2.13 E-18	7.11 E-21	1.28 E-17	2.18 E-17
2.0 E 03	1.86 E-18	5.21 E-21	1.06 E-17	1.80 E-17
2.5 E 03	1.62 E-18	4.40 E-21	8.90 E-18	1.56 E-17
3.0 E 03	1.42 E-18		7.50 E-18	1.39 E-17
6.0 E 03	7.91 E-19			
1.0 E 04	5.29 E-19			
2.0 E 04	2.91 E-19			
2.5 E 04	2.38 E-19			

References:

$e + \text{Li}^+$ (single ionization): W.C. Lineberger, J.W. Hooper, and E.W. McDaniel, Phys. Rev. 141, 151 (1966). B. Peart and K.T. Dolder, J. Phys. B 1, 872 (1968). B. Peart, D.S. Walton, and K.T. Dolder, J. Phys. B 2, 1347 (1969).

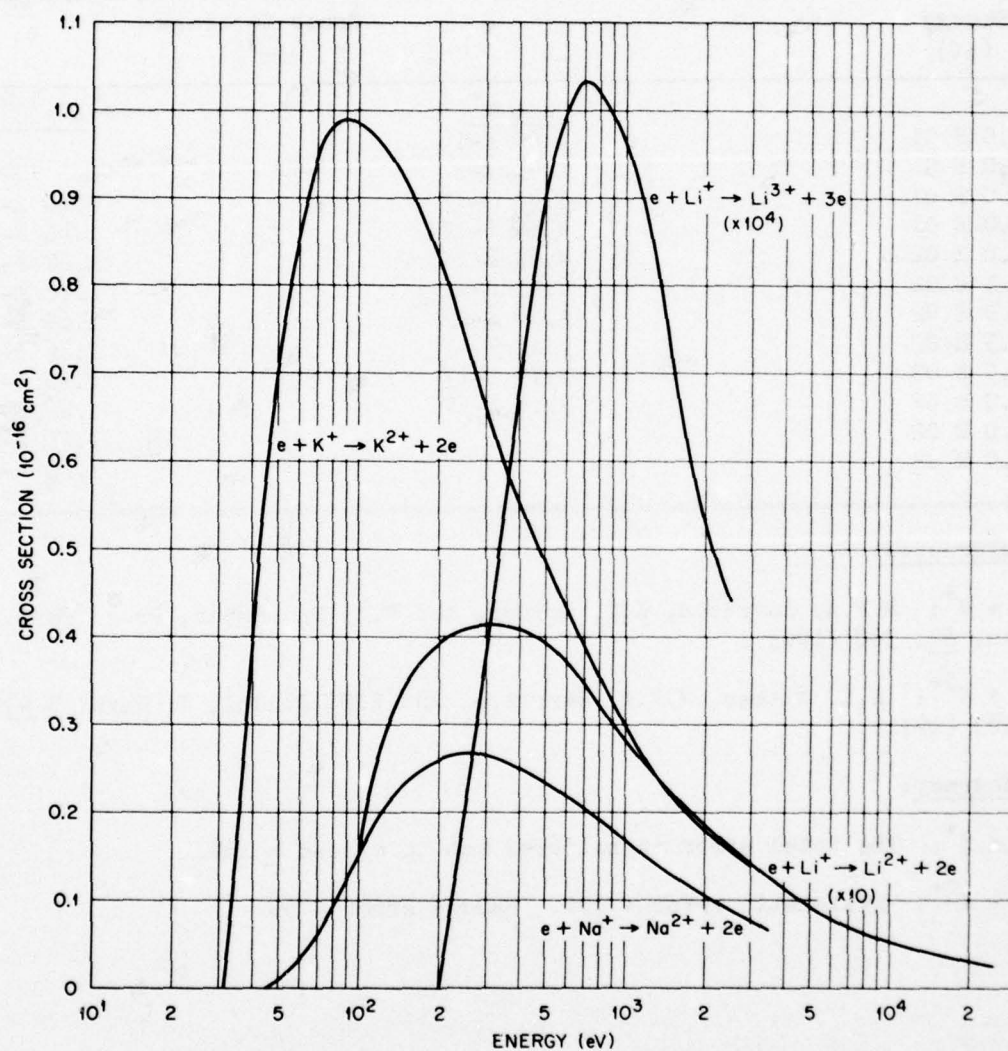
$e + \text{Li}^+$ (double ionization): B. Peart and K.T. Dolder, J. Phys. B 2, 1169 (1969).

$e + (\text{Na}^+, \text{K}^+)$: B. Peart and K.T. Dolder, J. Phys. B 1, 240 (1968). J.W. Hooper, W.C. Lineberger, and F.M. Bacon, Phys. Rev. 141, 165 (1966).

Accuracy:

$e + \text{Li}^+$ (single ionization): systematic error $< \pm 8\%$, random error $< \pm 6\%$ over most of energy range. $e + \text{Li}^+$ (double ionization): systematic error $< \pm 9\%$, random error $< \pm 9\%$. $e + \text{Na}^+$: maximum total error $= \pm 6\%$ for $E \leq 2000$ eV; $\pm 10\%$ at $E = 3500$ eV. $e + \text{K}^+$: maximum total error $= \pm 6\%$ at $E \leq 1250$ eV; $\pm 9\%$ at $E = 3000$ eV.

Cross Sections for Single and Double Ionization of Li^+ Ions and
Cross Sections for Single Ionization of Na^+ and K^+ Ions by Electron Impact



Graphical Data C-4.30.

Tabular Data C-4.31.

Cross Sections for Single Ionization of N^+ and N^{2+}

Ions by Electron Impact

Energy (eV)	Cross Sections (cm ²)	
	$e + N^+$	$e + N^{2+}$
3.0 E 01	1.00 E-18	
4.0 E 01	1.91 E-17	
6.0 E 01	3.65 E-17	7.80 E-18
8.0 E 01	4.56 E-17	1.41 E-17
1.0 E 02	4.99 E-17	1.67 E-17
1.5 E 02	4.85 E-17	1.76 E-17
2.0 E 02	4.50 E-17	1.69 E-17
2.5 E 02	4.13 E-17	1.56 E-17
3.0 E 02	3.79 E-17	1.45 E-17
4.0 E 02	3.16 E-17	1.26 E-17
6.0 E 02		9.70 E-18
8.0 E 02		7.80 E-18

References:

$e + N^+$: M.F.A. Harrison, K.T. Dolder, and P.C. Thonemann, Proc. Phys. Soc. 82, 368 (1963).

$e + N^{2+}$: K.L. Aitken, M.F.A. Harrison, and R.D. Rundel, J. Phys. B 4, 1189 (1971).

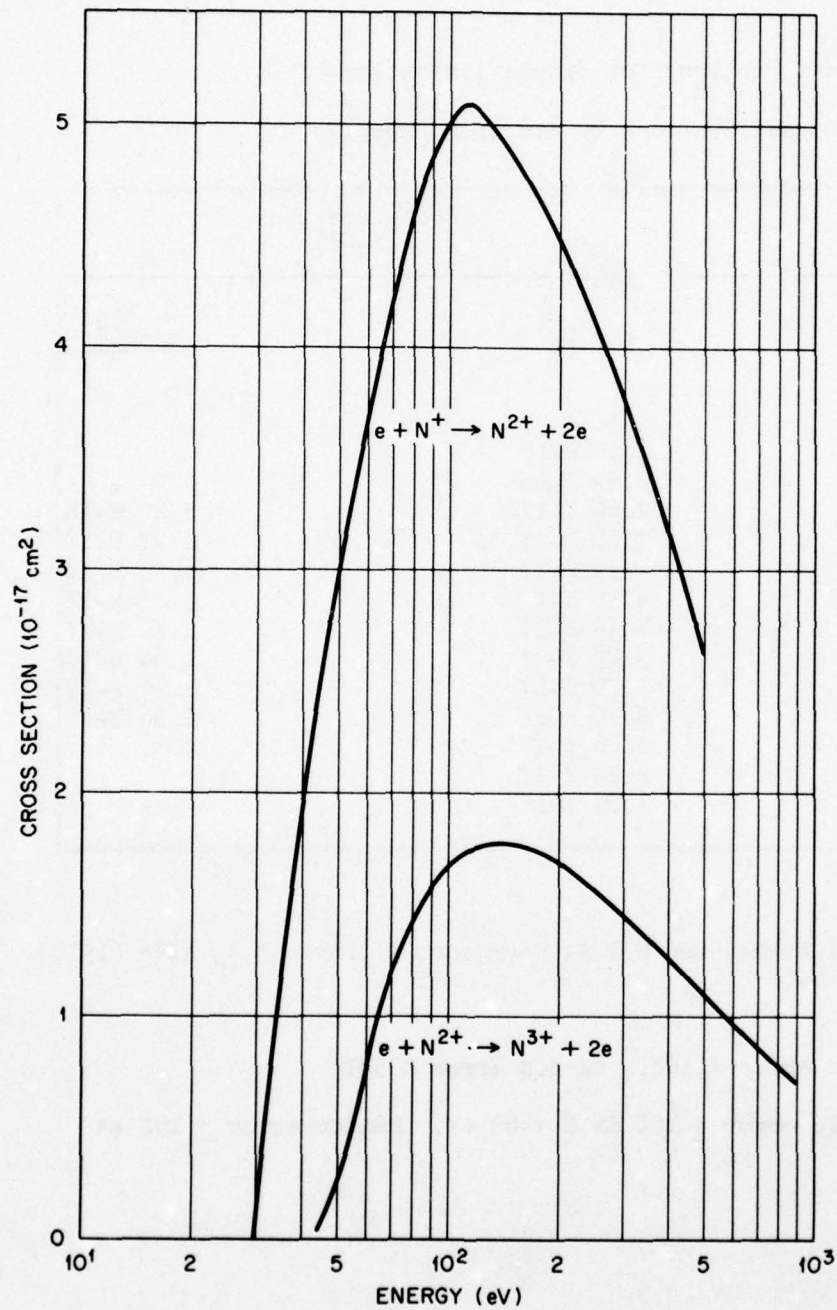
Accuracy:

$e + N^+$: The total error is believed not to exceed $\pm 15\%$.

$e + N^{2+}$: Systematic error $< 10\%$. Random error $< 5\%$.

Cross Sections for Single Ionization of N^+ and N^{2+}

Ions by Electron Impact



Graphical Data C-4.32.

Tabular Data C-4.33.

Cross Sections for Single Ionization of
 O^+ and O^{2+} Ions by Electron Impact

Energy (eV)	Cross Sections (cm ²)	
	<u>$e + O^+$</u>	<u>$e + O^{2+}$</u>
2.5 E 01	5.00 E-20	
3.0 E 01	2.50 E-19	
4.0 E 01	6.89 E-18	
6.0 E 01	2.64 E-17	5.20 E-18
8.0 E 01	3.68 E-17	1.27 E-17
1.0 E 02	4.19 E-17	1.65 E-17
1.5 E 02	4.38 E-17	1.82 E-17
2.0 E 02	4.19 E-17	1.76 E-17
2.5 E 02	3.93 E-17	1.66 E-17
3.0 E 02	3.70 E-17	1.56 E-17
4.0 E 03	3.29 E-17	1.36 E-17
6.0 E 02	2.66 E-17	
8.0 E 02	2.21 E-17	
1.0 E 03	1.85 E-17	

Reference:

$e + (O^+, O^{2+})$: K.L. Aitken and M.F.A. Harrison, J. Phys. B 4, 1176 (1971).

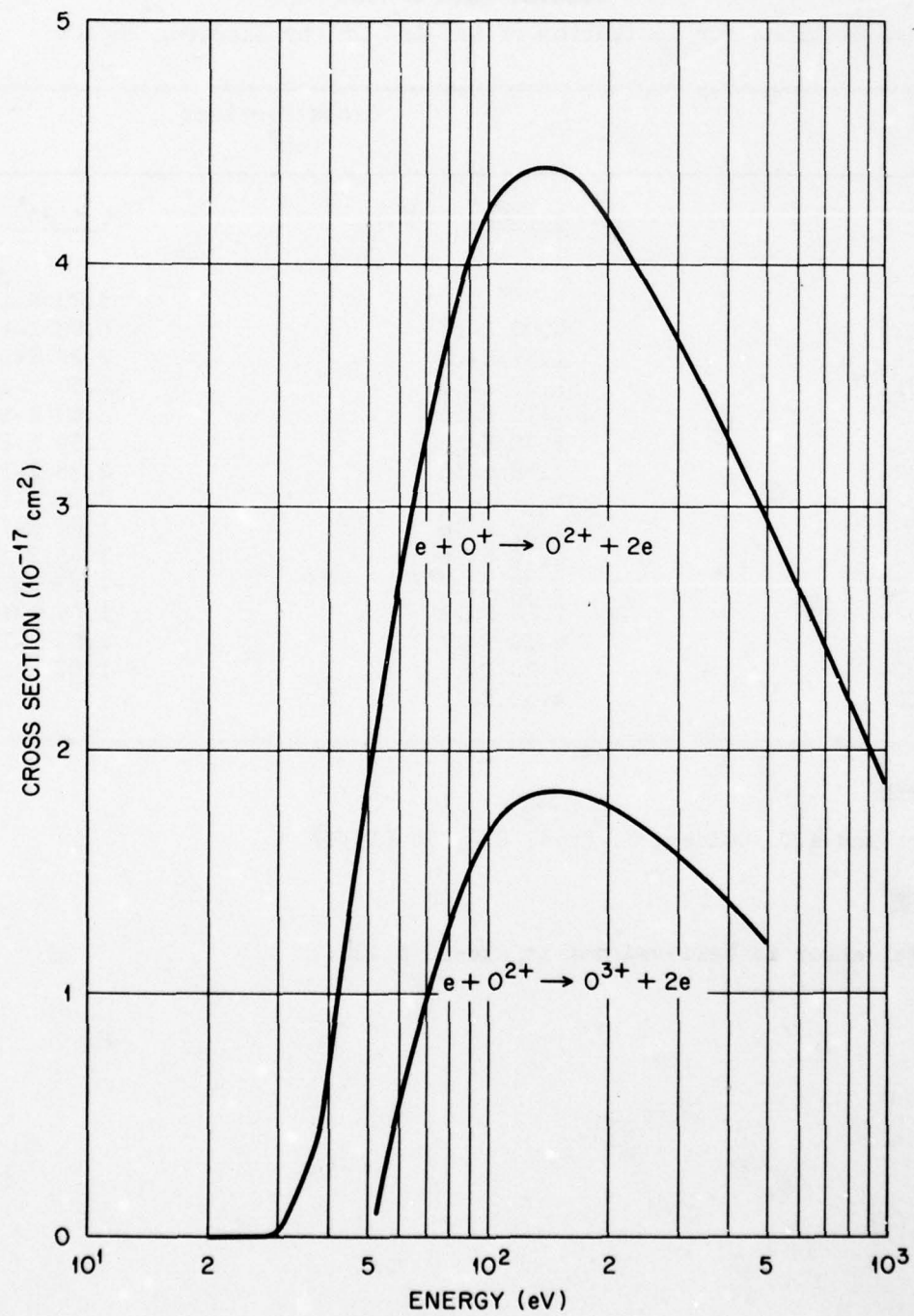
Accuracy:

$e + O^+$: Systematic error < 10%. Random error < 5%.

$e + O^{2+}$: Systematic error \leq 15% at $E < 63$ eV. Random error \leq 15% at $E < 63$ eV.

Cross Sections for Single Ionization of

O^+ and O^{2+} Ions by Electron Impact



Graphical Data C-4.34.

Tabular Data C-4.35

Cross Sections for Ionization of Ca^+ and Sr^+ by Electron Impact

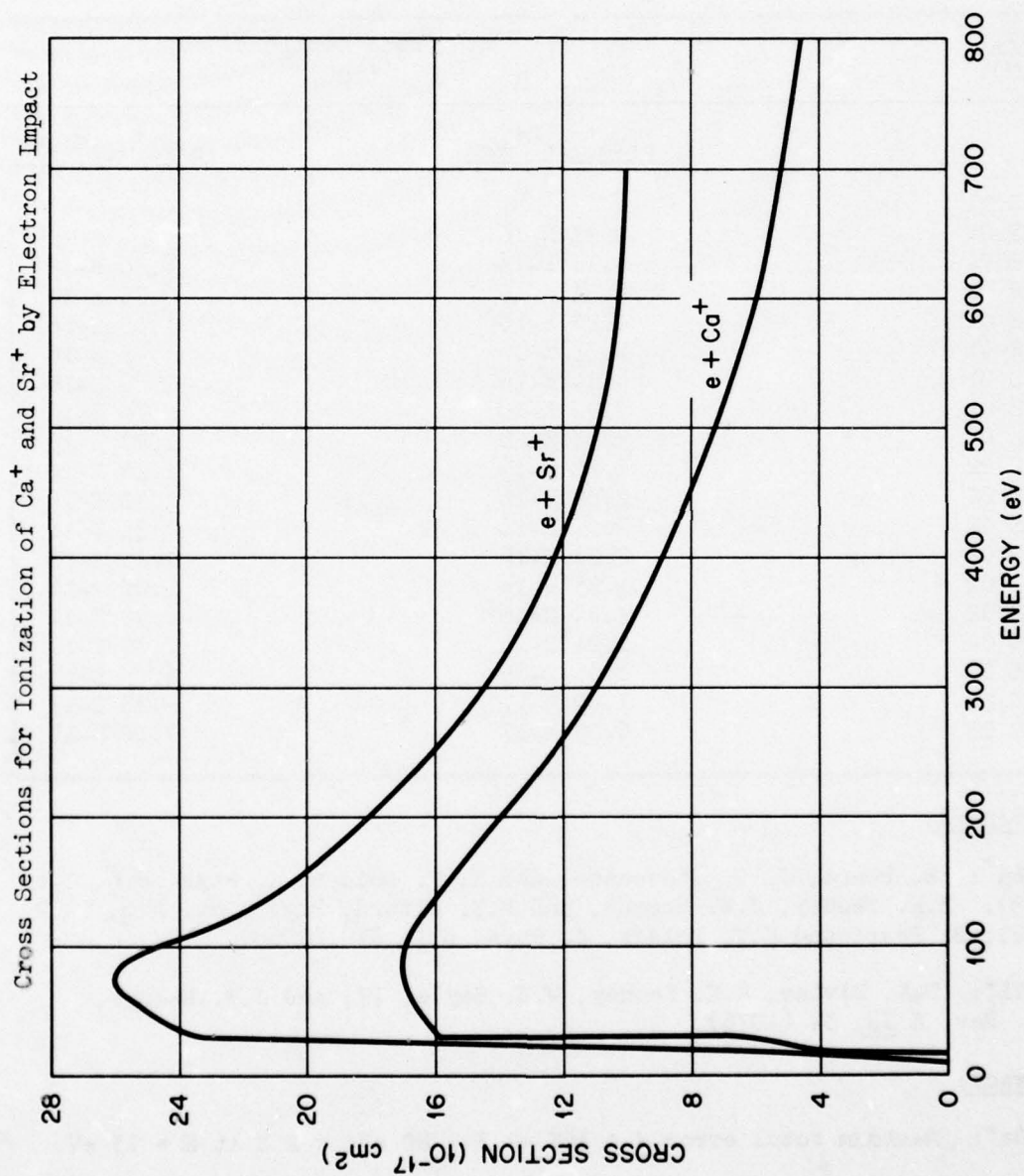
Energy (eV)	Cross Sections (cm^2)	
	<u>$e + \text{Ca}^+$</u>	<u>$e + \text{Sr}^+$</u>
1.7 E 01		5.20 E-17
2.0 E 01	4.00 E-17	8.00 E-17
3.0 E 01	1.59 E-16	2.20 E-16
5.0 E 01	1.65 E-16	2.50 E-16
7.5 E 01	1.70 E-16	2.60 E-16
8.0 E 01	1.70 E-16	2.59 E-16
1.1 E 02	1.68 E-16	2.36 E-16
1.5 E 02	1.56 E-16	2.04 E-16
2.0 E 02	1.40 E-16	1.82 E-16
3.0 E 02	1.10 E-16	1.45 E-16
4.0 E 02	9.00 E-17	1.23 E-16
5.0 E 02	7.20 E-17	1.09 E-16
6.0 E 02	6.00 E-17	1.03 E-16
7.0 E 02	5.20 E-17	1.00 E-16
8.0 E 02	4.50 E-17	

Reference:

B. Peart and K.T. Dolder, J. Phys. B 8, 56 (1975).

Accuracy:

The total error is believed not to exceed $\pm 12\%$.



Graphical Data C-4.36.

Tabular Data C-4.37.
Cross Sections for Single Ionization of Ba⁺ and Tl⁺
Ions by Electron Impact

Energy (eV)	Cross Sections (cm ²)	
	<u>e+Ba⁺→Ba²⁺+2e</u>	<u>e+Tl⁺→Tl²⁺+2e</u>
1.0 E 01		
1.5 E 01	1.31 E-16	
2.0 E 01	4.10 E-16	4.20 E-17
2.5 E 01	4.31 E-16	6.75 E-17
3.0 E 01	4.37 E-16	1.05 E-16
4.0 E 01	4.33 E-16	1.45 E-16
6.0 E 01	4.14 E-16	1.68 E-16
8.0 E 01	3.92 E-16	1.74 E-16
1.0 E 02	3.72 E-16	1.75 E-16
1.5 E 02	3.26 E-16	1.16 E-16
2.0 E 02	2.85 E-16	1.50 E-16
2.5 E 02	2.50 E-16	1.35 E-16
3.0 E 02	2.20 E-16	1.25 E-16
4.0 E 02	1.85 E-16	1.08 E-16
6.0 E 02	1.44 E-16	8.90 E-17
8.0 E 02	1.21 E-16	7.70 E-17
1.0 E 03	1.05 E-16	6.75 E-17
1.5 E 03	7.80 E-17	5.20 E-17
2.0 E 03	6.10 E-17	4.10 E-17

References:

e + Ba⁺: B. Peart, J. G. Stevenson, and K. T. Dolder, J. Phys. B 6, 146 (1973). R.K. Feeney, J.W. Hooper, and M.T. Elford, Phys. Rev. A 6, 1469 (1972); B. Peart and K.T. Dolder, J. Phys. B 1, 872 (1968).

e + Tl⁺: T.F. Divine, R.K. Feeney, W.E. Sayle, II, and J.W. Hooper, Phys. Rev. A 13, 54 (1976).

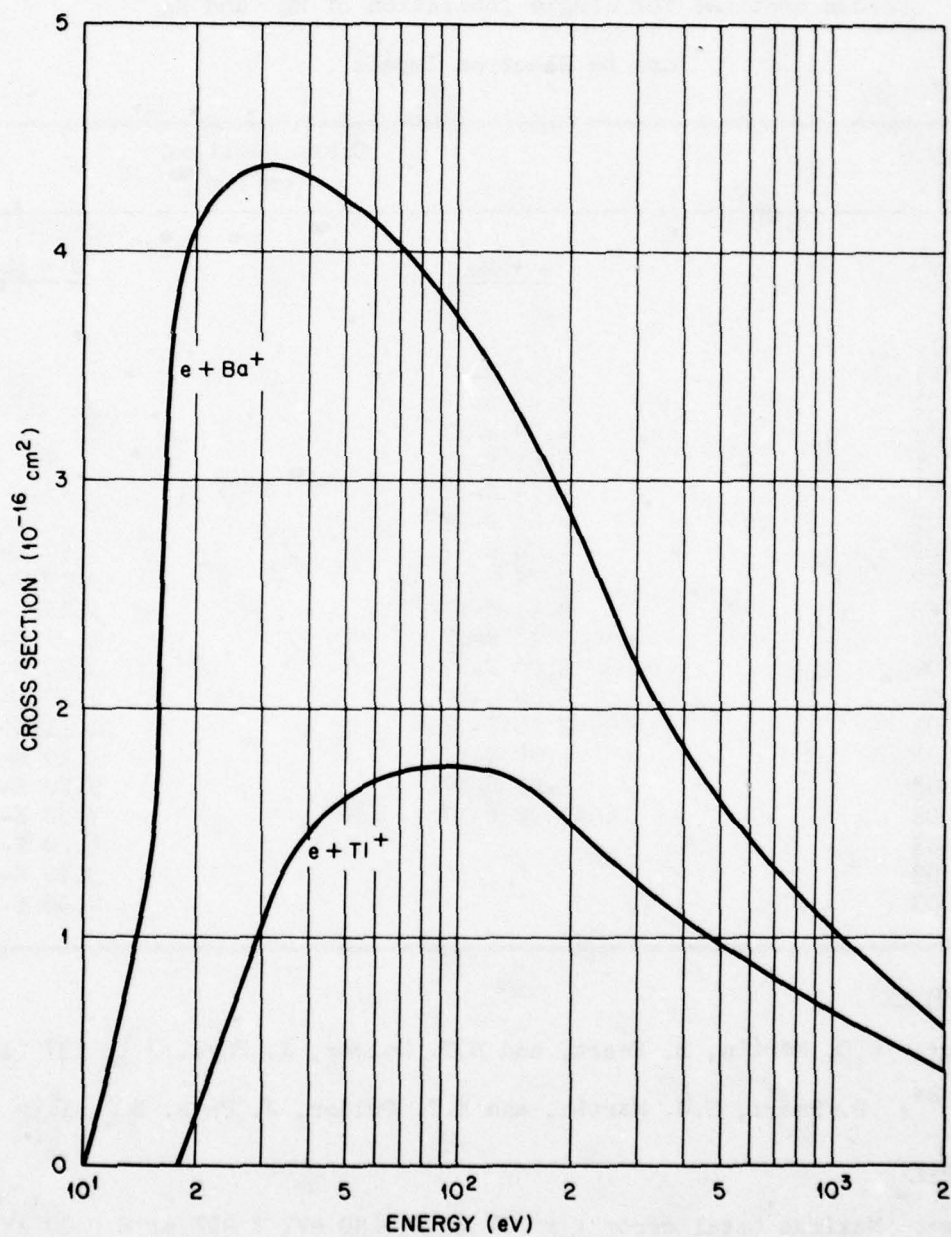
Accuracy:

e + Ba⁺: Maximum total error $\leq \pm 10\%$ at E ≥ 20 eV; $\pm 25\%$ at E = 15 eV.

e + Tl⁺: The total error is believed not to exceed $\pm 15\%$.

Cross Sections for Single Ionization of Ba^+ and Tl^+

Ions by Electron Impact



Graphical Data C-4.38.

Tabular Data C-4.39.
 Cross Sections for Single Ionization of Mg^+ and Mg^{2+}
 Ions by Electron Impact

Energy (eV)	Cross Sections (cm^2)	
	<u>$e + Mg^+$</u>	<u>$e + Mg^{2+}$</u>
2.0 E 01	3.30 E-17	
2.5 E 01	4.45 E-17	
3.0 E 01	4.79 E-17	
4.0 E 01	4.81 E-17	
6.0 E 01	4.54 E-17	
8.0 E 01	4.28 E-17	
1.0 E 02	4.08 E-17	2.70 E-18
1.5 E 02	3.70 E-17	9.19 E-18
2.0 E 02	3.41 E-17	1.15 E-17
2.5 E 02	3.18 E-17	1.25 E-17
3.0 E 02	3.00 E-17	1.30 E-17
4.0 E 02	2.69 E-17	1.30 E-17
6.0 E 02	2.25 E-17	1.21 E-17
8.0 E 02	1.94 E-17	1.19 E-17
1.0 E 03	1.69 E-17	9.70 E-18
1.5 E 03	1.22 E-17	7.50 E-18
2.0 E 03		6.20 E-18
2.5 E 03		5.40 E-18
3.0 E 03		4.90 E-18

References:

$e + Mg^+$: S.O. Martin, B. Peart, and K.T. Dolder, J. Phys. B 1, 537 (1968).

$e + Mg^{2+}$: B. Peart, S.O. Martin, and K.T. Dolder, J. Phys. B 2, 1176 (1969).

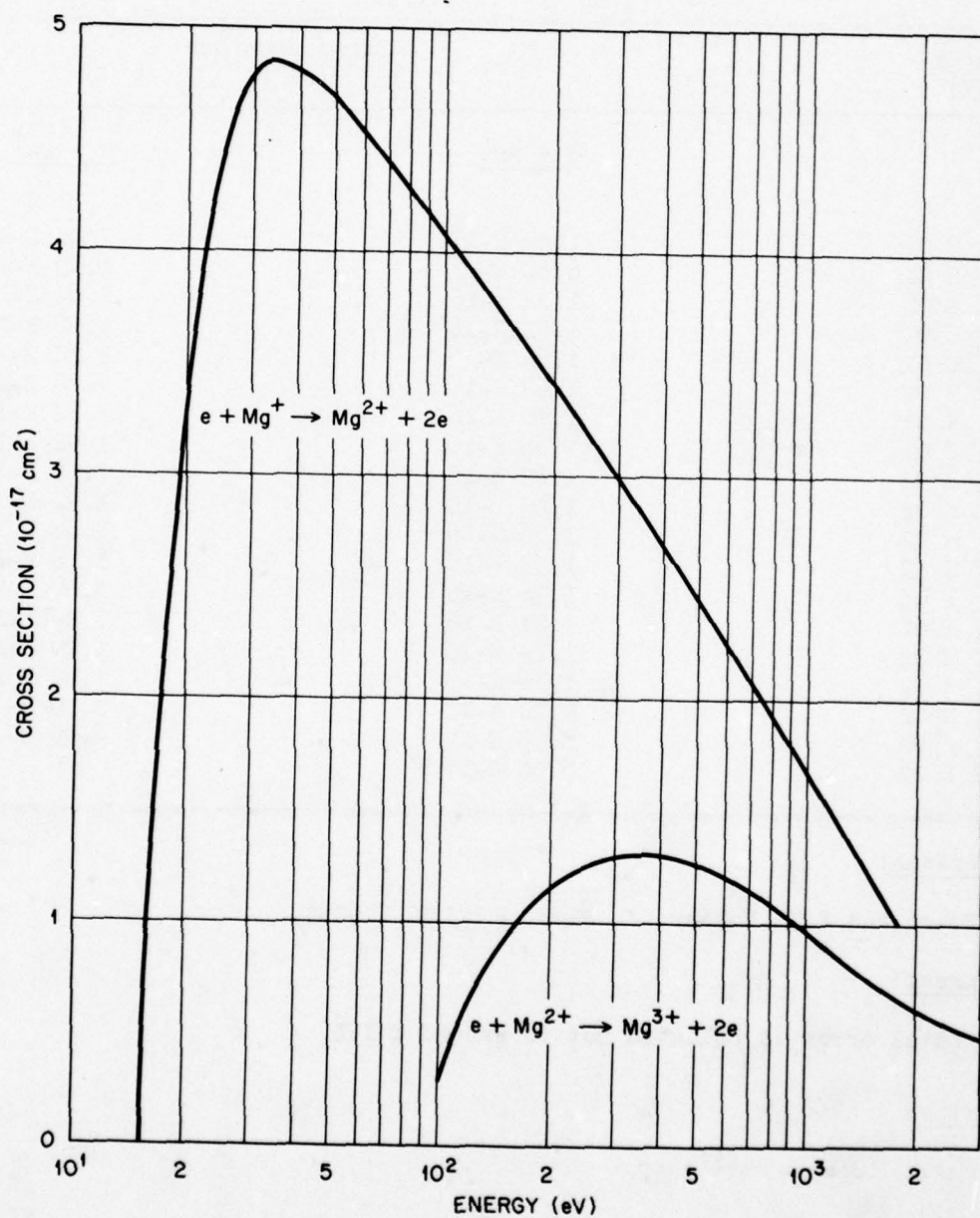
Accuracy:

$e + Mg^+$: Maximum total error $\leq \pm 10\%$ at $E \geq 50$ eV; $\pm 20\%$ at $E = 20$ eV.

$e + Mg^{2+}$: Systematic error $< \pm 8\%$. Random error $< \pm 5\%$.

Cross Sections for Single Ionization of Mg^+ and Mg^{2+}

Ions by Electron Impact



Graphical Data C-4.40.

Tabular Data C-4.41.

Cross Sections for Ionization of Rb^+ and Cs^+ Ions by Electron Impact

Energy (eV)	Cross Sections (cm^2)	
	$e + \text{Rb}^+$	$e + \text{Cs}^+$
3.0 E 01	1.60 E-17	7.00 E-17
4.0 E 01	6.60 E-17	1.40 E-16
5.0 E 01	1.32 E-16	1.62 E-16
6.0 E 01	1.52 E-16	1.68 E-16
7.0 E 01	1.64 E-16	1.72 E-16
7.5 E 01	1.68 E-16	1.76 E-16
8.0 E 01	1.70 E-16	1.82 E-16
9.0 E 01	1.66 E-16	1.92 E-16
1.0 E 02	1.63 E-16	1.95 E-16
1.1 E 02	1.69 E-16	1.92 E-16
1.2 E 02	1.66 E-16	1.86 E-16
1.3 E 02	1.53 E-16	1.78 E-16
1.5 E 02	1.36 E-16	1.60 E-16
2.0 E 02	1.21 E-16	1.30 E-16
2.25 E 02	1.19 E-16	1.20 E-16
2.5 E 02	1.16 E-16	1.06 E-16
3.5 E 02	9.20 E-17	7.10 E-17
4.0 E 02	8.50 E-17	6.00 E-17
4.75 E 02	8.00 E-17	

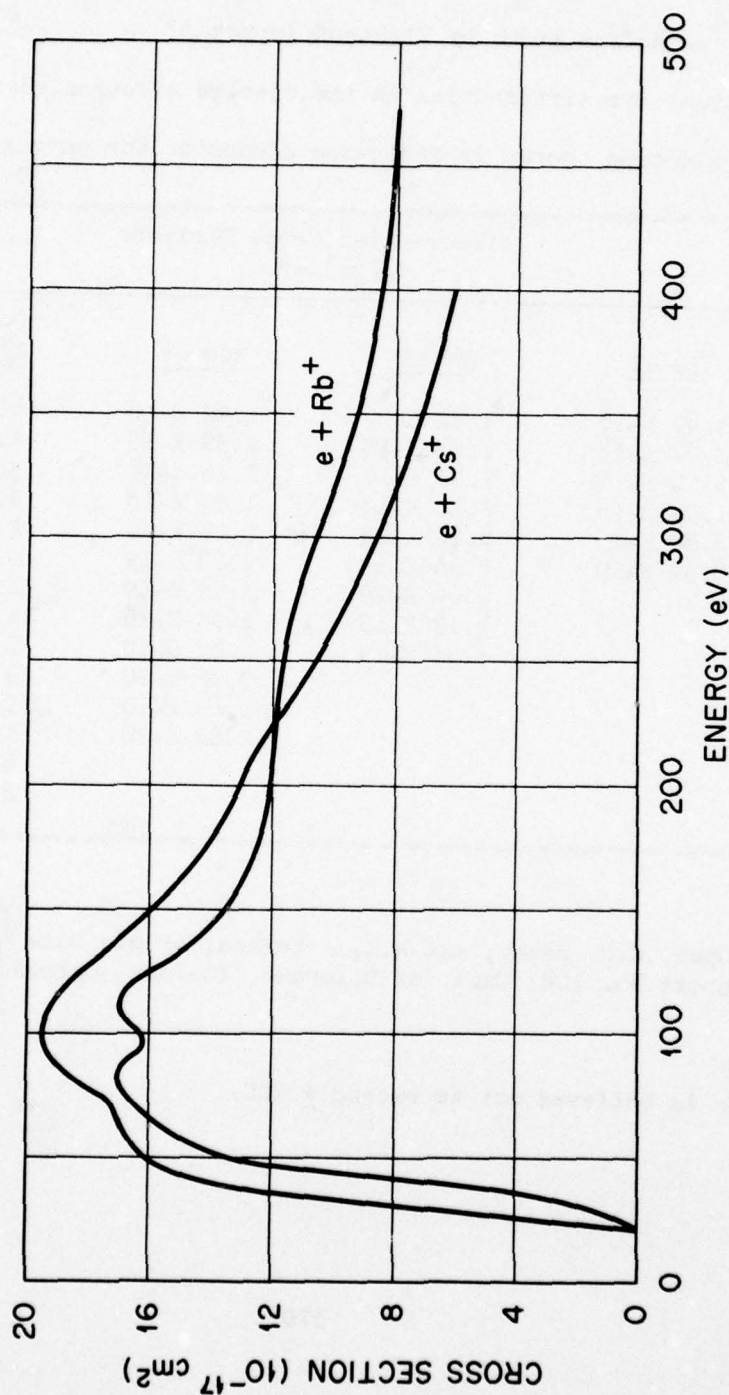
Reference:

B. Peart and K.T. Dolder, J. Phys. B 8, 56 (1975).

Accuracy:

The total error is believed not to exceed $\pm 12\%$.

Cross Sections for Ionization of Rb^+ and Cs^+ Ions by Electron Impact



Graphical Data C-4.42.

Tabular Data C-4.43.

Differential Cross Sections for Ejection of Electrons from

Helium Atoms by Electron Impact

(The cross sections are differential in the ejected electron energy.

The incident electron energy is indicated alongside the curves.)

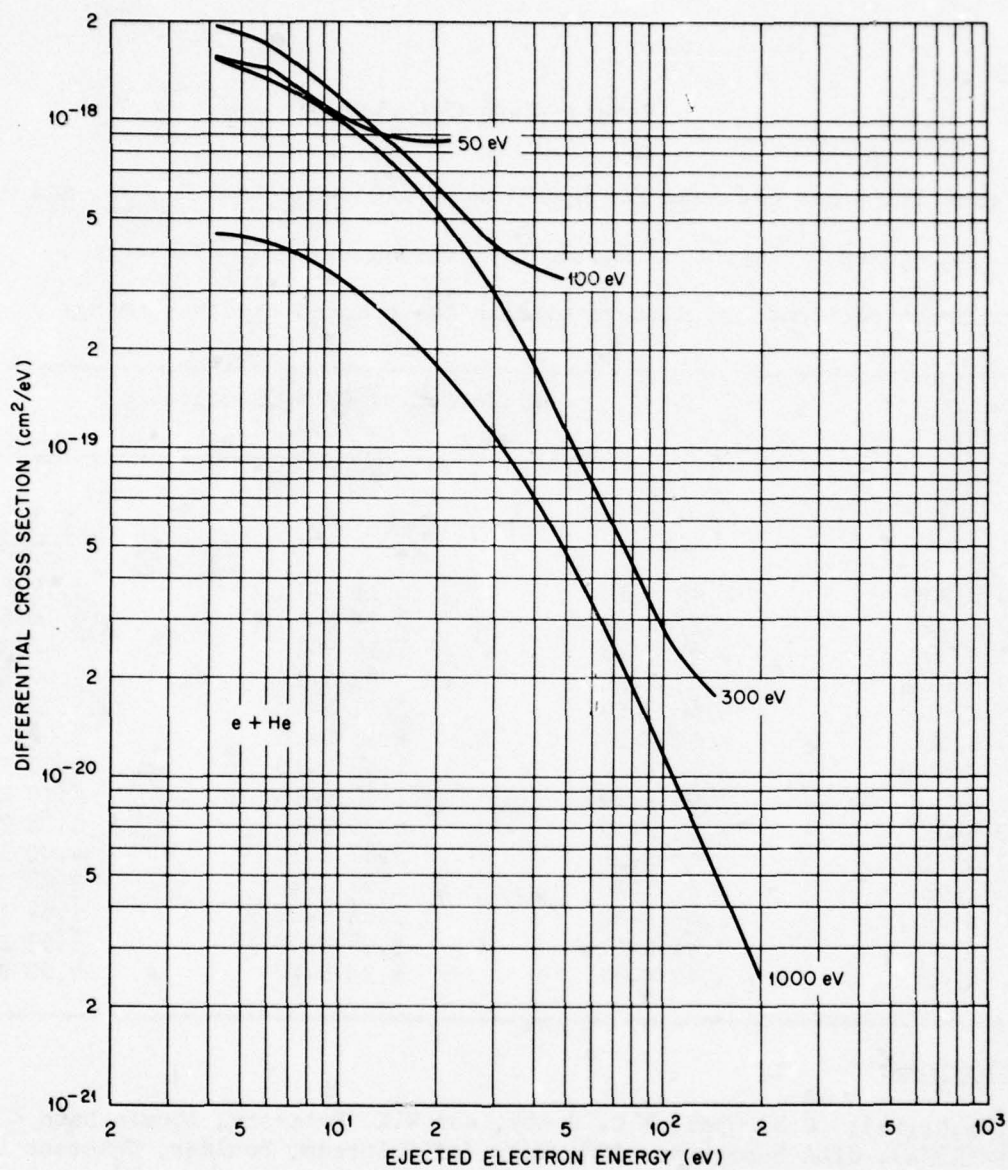
Energy (eV)	Differential Cross Sections (cm ² /eV)			
	50 eV	100 eV	300 eV	1000 eV
5.0 E 00	1.49 E-18	1.82 E-18	1.42 E-18	4.40 E-19
6.0 E 00	1.44 E-18	1.71 E-18	1.32 E-18	4.42 E-19
8.0 E 00	1.20 E-18	1.40 E-18	1.15 E-18	3.78 E-19
1.0 E 01	1.04 E-18	1.18 E-18	1.00 E-18	3.30 E-19
1.5 E 01	8.80 E-19	8.20 E-19	7.17 E-19	2.39 E-19
2.0 E 01	8.59 E-19	6.26 E-19	5.20 E-19	1.79 E-19
2.5 E 01		5.00 E-19	3.89 E-19	1.39 E-19
3.0 E 01		4.17 E-19	3.00 E-19	1.09 E-19
4.0 E 01		3.57 E-19	1.80 E-19	7.00 E-20
6.0 E 01			7.88 E-20	3.39 E-20
8.0 E 01			4.43 E-20	1.90 E-20
1.0 E 02			2.82 E-20	1.18 E-20
1.5 E 02				4.76 E-21
2.0 E 02				2.46 E-21

References:

e + He: C.B. Opal, E.C. Beaty, and W.K. Peterson, Atomic Data 4, 209 (1972); JILA Report No. 108, Univ. of Colorado, Boulder, Colorado (1971).

Accuracy:

The total error is believed not to exceed \pm 30%.



Differential Cross Sections for Ejection of Electrons from
Helium Atoms by Electron Impact

(The cross sections are differential in the ejected electron energy.

The incident electron energy is indicated alongside the curves.)

Graphical Data C-4.44.

Tabular Data C-4.45.

Differential Cross Sections for Ejection of Electrons from H_2 , N_2 , and O_2

Molecules by Impact of Incident Electrons with 500 eV Energy

(The cross sections are differential in the ejected electron energy.)

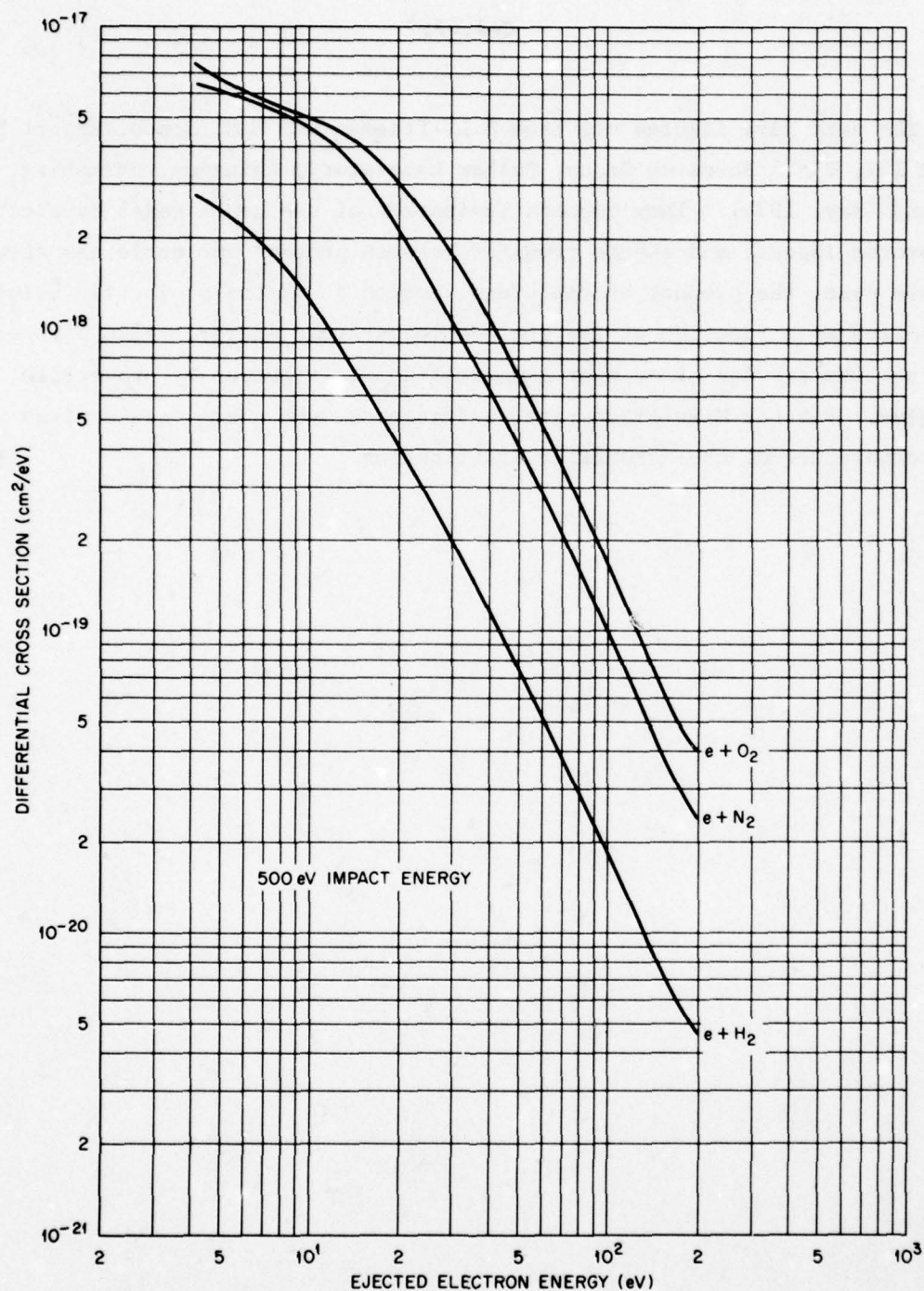
Energy (eV)	Differential Cross Section (cm^2/eV)		
	$e + H_2$	$e + N_2$	$e + O_2$
5.0 E 00	2.49 E-18	6.11 E-18	6.79 E-18
6.0 E 00	2.17 E-18	5.77 E-18	6.16 E-18
8.0 E 00	1.64 E-18	5.19 E-18	5.42 E-18
1.0 E 01	1.23 E-18	4.63 E-18	5.00 E-18
1.5 E 01	6.60 E-19	3.21 E-18	4.00 E-18
2.0 E 01	4.04 E-19	2.10 E-18	3.02 E-18
2.5 E 01	2.74 E-19	1.44 E-18	2.30 E-18
3.0 E 01	1.98 E-19	1.06 E-18	1.75 E-18
4.0 E 01	1.13 E-19	6.30 E-19	1.08 E-18
6.0 E 01	5.18 E-20	2.88 E-19	4.90 E-19
8.0 E 01	2.89 E-20	1.60 E-19	2.70 E-19
1.0 E 02	1.80 E-20	9.83 E-20	1.64 E-19
1.5 E 02	7.48 E-21	3.98 E-20	6.53 E-20
2.0 E 02	4.60 E-21	2.38 E-20	4.00 E-20

References:

$e+(H_2,N_2,O_2)$: C.B. Opal, E.C. Beaty, and W.K. Peterson, Atomic Data 4, 209 (1972); JILA Report No. 108, Univ. of Colorado, Boulder, Colorado (1971).

Accuracy:

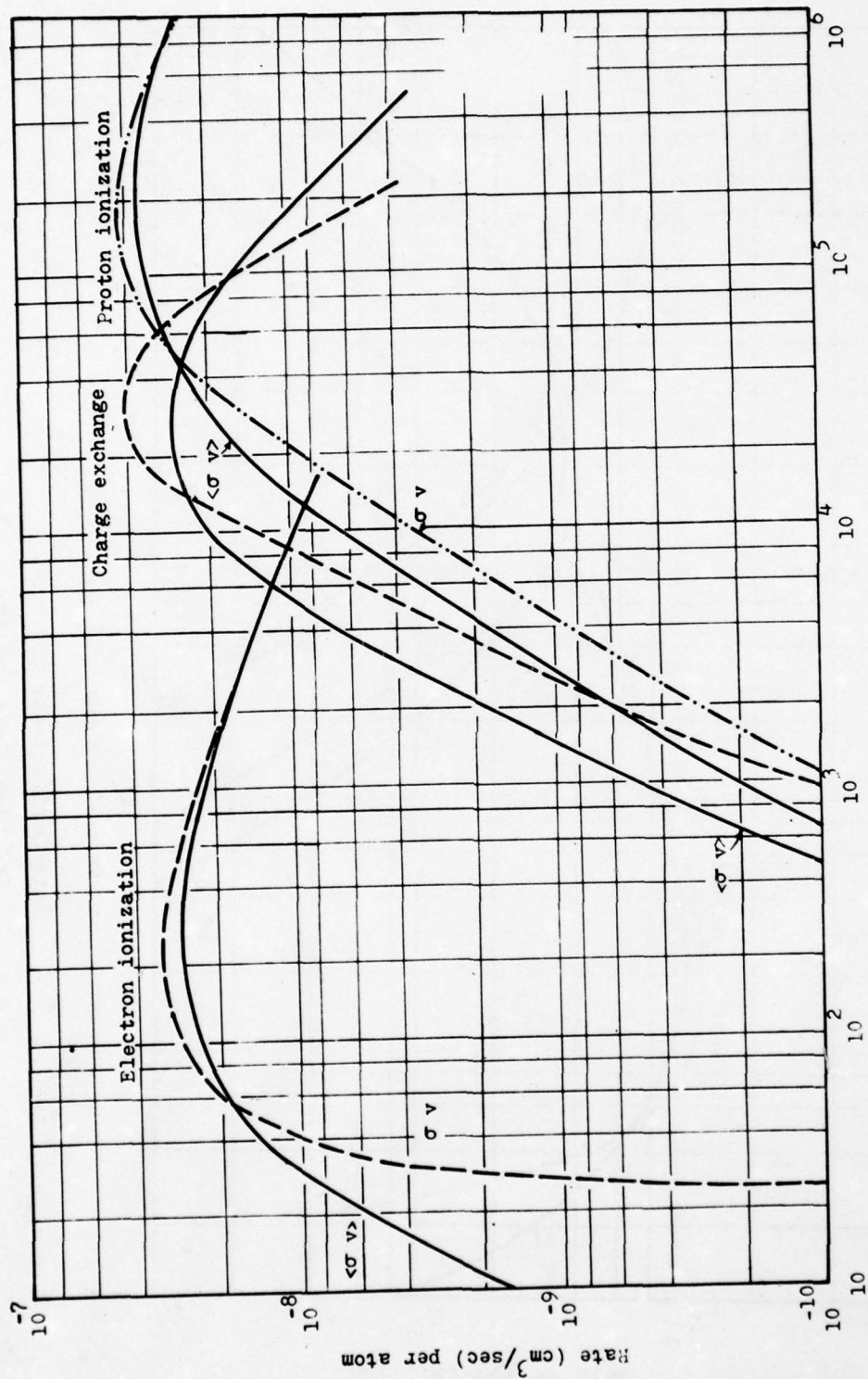
$e+(H_2,N_2,O_2)$: The total error is believed not to exceed $\pm 30\%$.



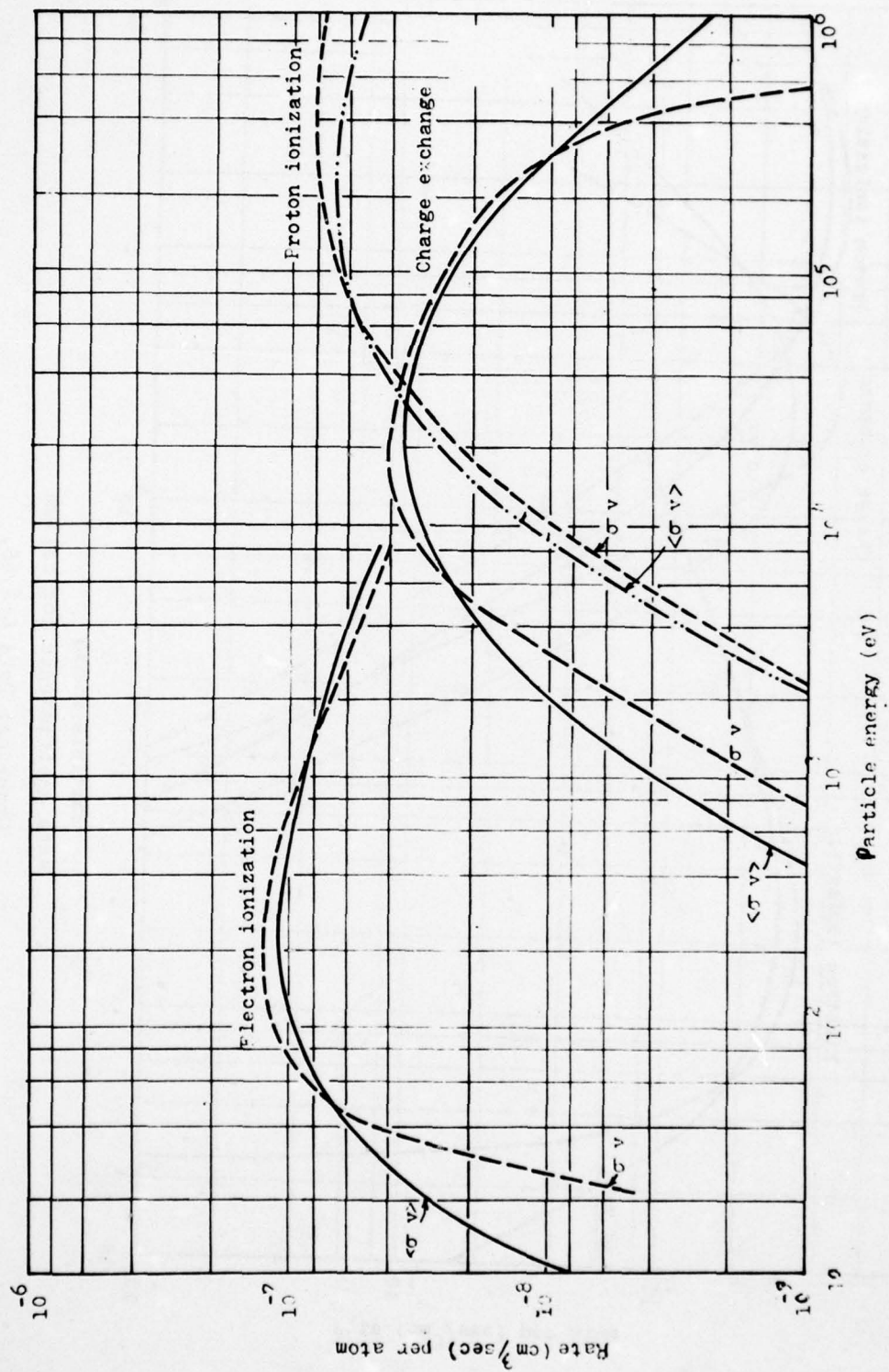
Differential Cross Sections for Ejection of Electrons from H_2 , N_2 , and O_2 Molecules by Impact of Incident Electrons with 500 eV Energy
(The cross sections are differential in the ejected electron energy.)
Graphical Data C-4.46.

C-4.47.

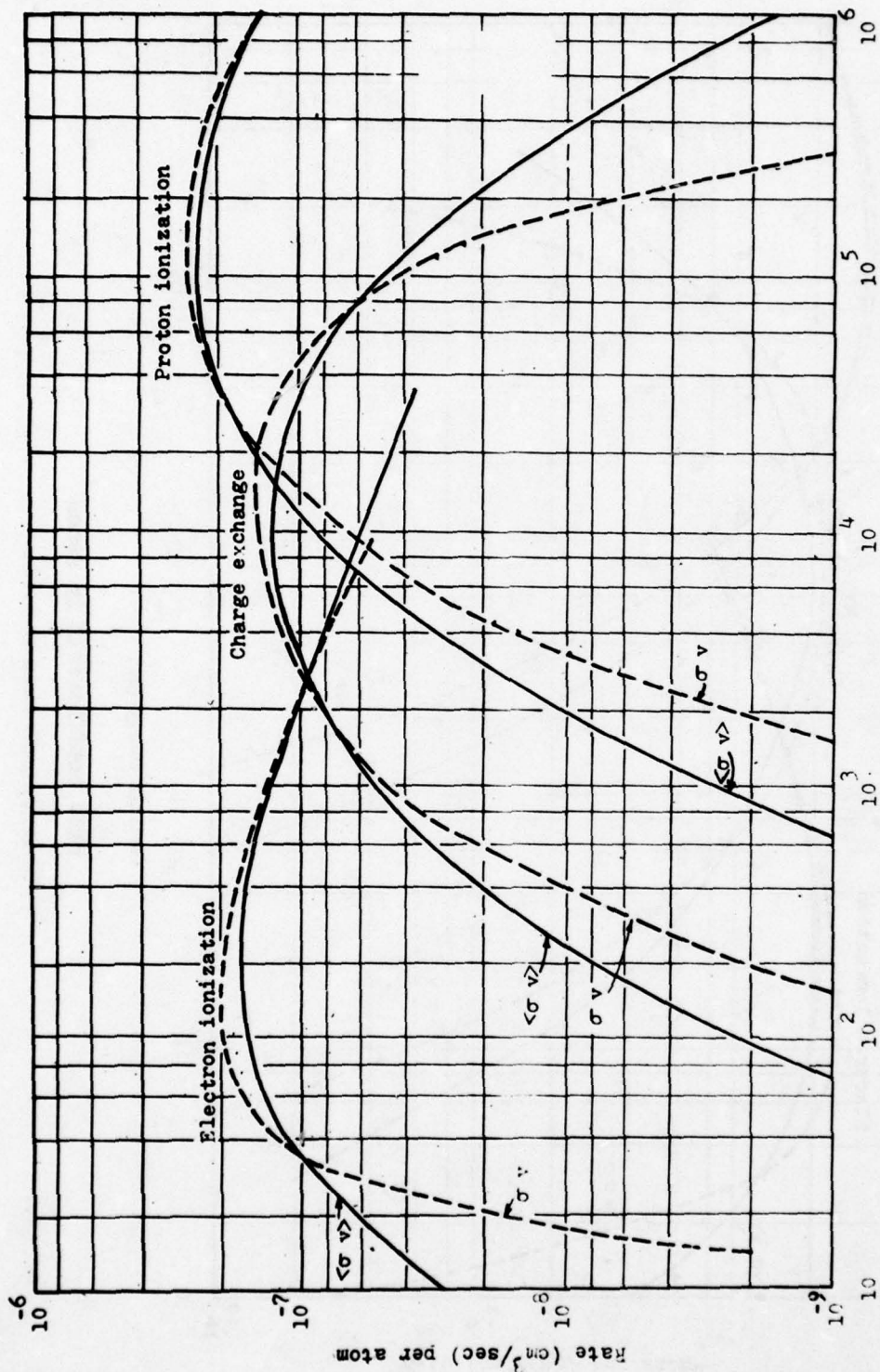
The next five figures are from R.L. Freeman and E.M. Jones, Report No. CLM-R 137, UKAEA Research Group, Culham Laboratory, Abingdon, Berkshire, England (May, 1974). They concern ionization of the noble gases by electron and proton impact, and charge transfer between protons and noble gas atoms. In each case, the product of the cross section σ and the projectile velocity v is plotted as a function of the projectile particle energy. Also plotted is $\langle\sigma v\rangle$, the average of σv over a Maxwellian distribution of projectile energies. For the Maxwellian rate coefficients, the energy scale gives the temperature of the Maxwellian distribution.



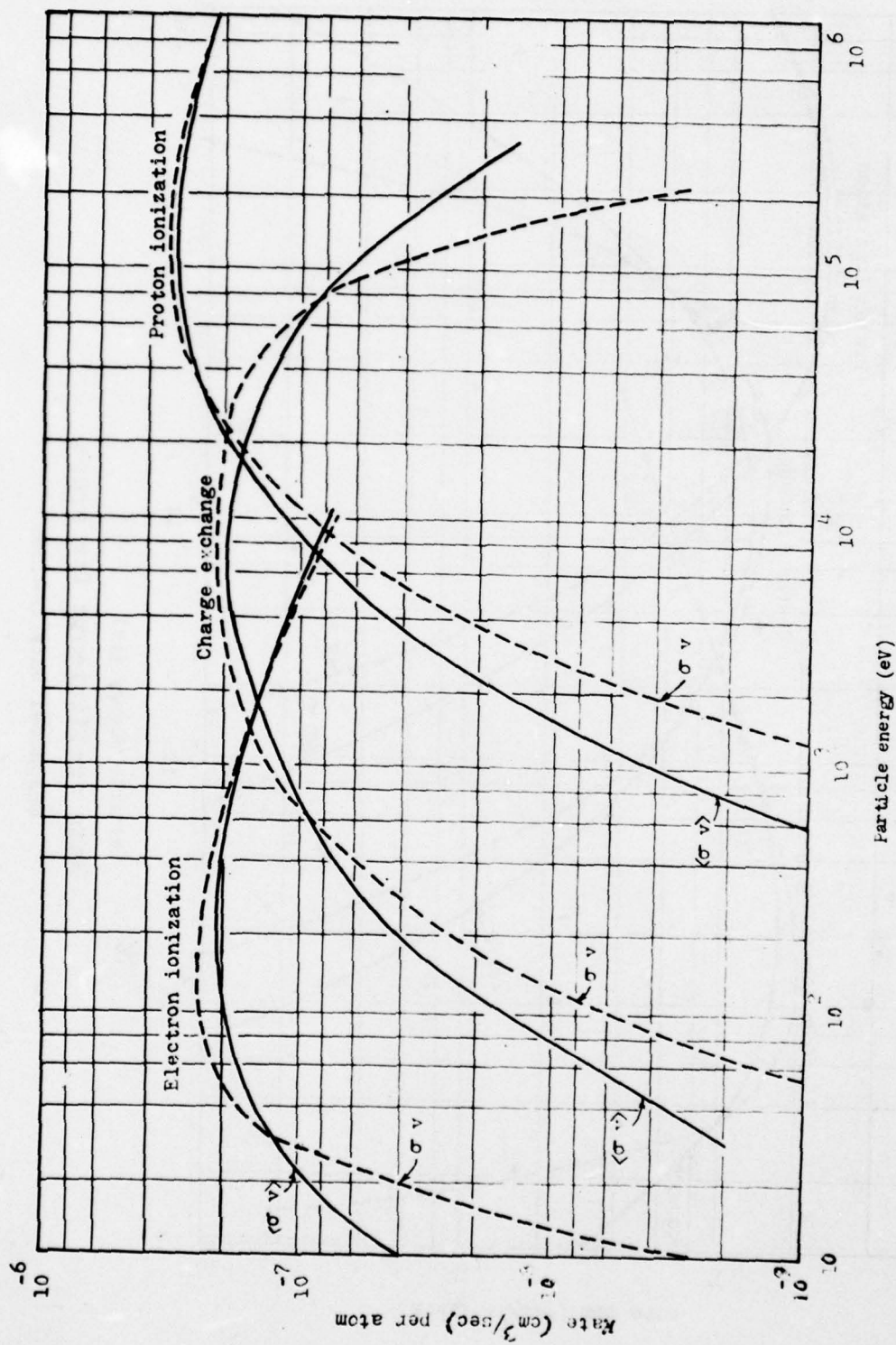
Rate coefficients for helium
Graphical Data C-4.48.



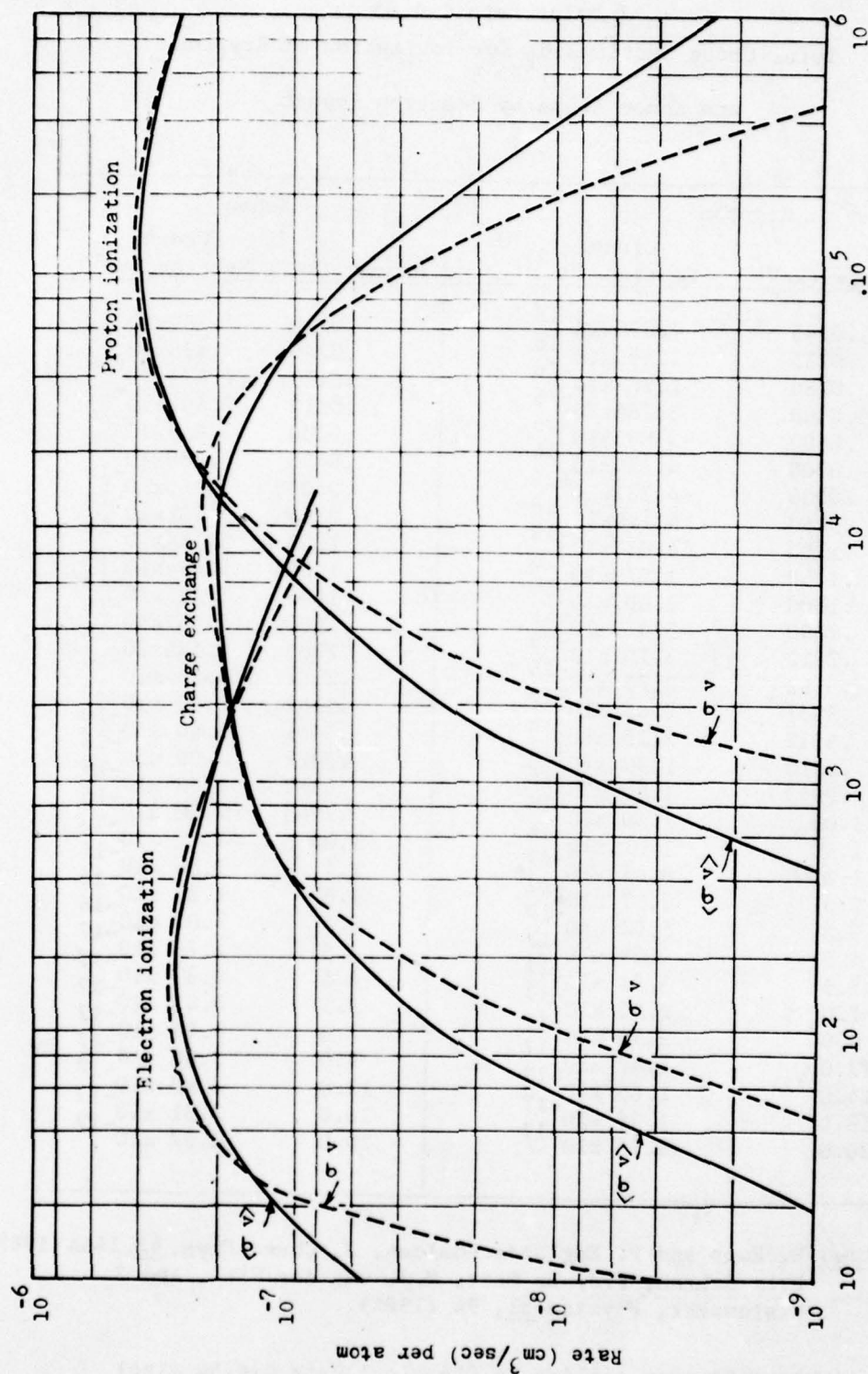
Rate Coefficients for neon
Graphical Data C-4.49.



Particle energy (ev)
 Rate coefficients for argon
 Graphical Data C-4.50.



Rate coefficients in xenon
Graphical Data C-4.51.



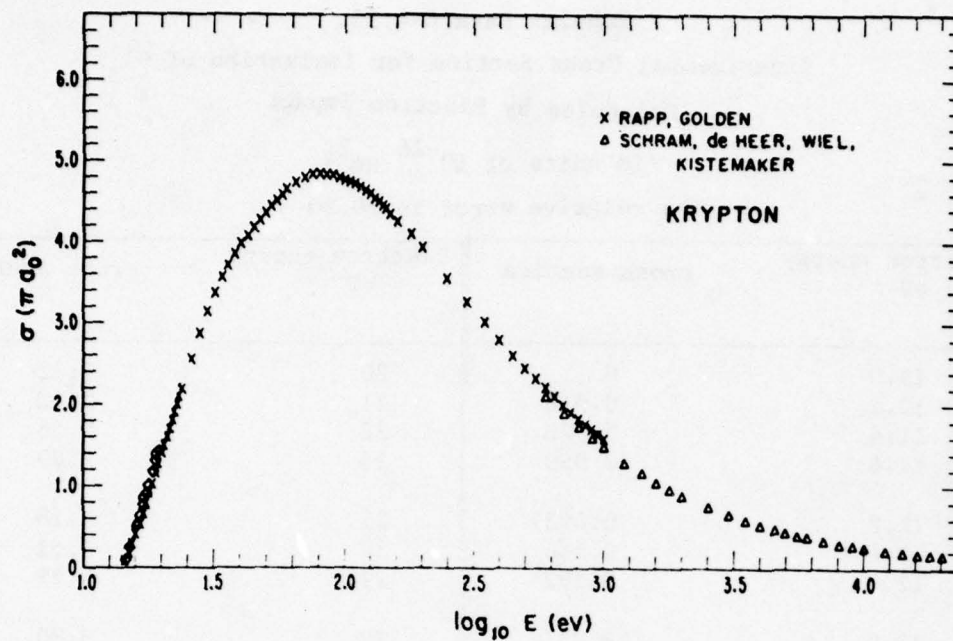
Particle energy (eV)
 Rate coefficients in xenon
 Graphical Data C-4.52.

Tabular Data C-4.53.
Total Cross Sections σ_T for Ionization of Krypton
and Xenon Atoms by Electron Impact

Krypton		Xenon	
Energy (keV)	Cross Section (cm ²)	Energy (keV)	Cross Section (cm ²)
.0145	7.829x10 ⁻¹⁸	.0125	1.100x10 ⁻¹⁷
.0215	1.495x10 ⁻¹⁶	.0145	7.425x10 ⁻¹⁷
.0280	2.525x10 ⁻¹⁶	.0175	1.671x10 ⁻¹⁶
.0360	3.264x10 ⁻¹⁶	.0210	2.49 x10 ⁻¹⁶
.0500	3.835x10 ⁻¹⁶	.0300	3.853x10 ⁻¹⁶
.0700	4.214x10 ⁻¹⁶	.0450	4.680x10 ⁻¹⁶
.0900	4.231x10 ⁻¹⁶	.0650	5.085x10 ⁻¹⁶
.1050	4.179x10 ⁻¹⁶	.0800	5.181x10 ⁻¹⁶
.1250	4.038x10 ⁻¹⁶	.1000	5.384x10 ⁻¹⁶
.1450	3.879x10 ⁻¹⁶	.1200	5.454x10 ⁻¹⁶
.1800	3.607x10 ⁻¹⁶	.1400	5.287x10 ⁻¹⁶
.2000	3.457x10 ⁻¹⁶	.1600	5.067x10 ⁻¹⁶
.2512	3.10 x10 ⁻¹⁶	.2000	4.583x10 ⁻¹⁶
.3162	2.75 x10 ⁻¹⁶	.2512	4.25 x10 ⁻¹⁶
.3981	2.45 x10 ⁻¹⁶	.3162	3.90 x10 ⁻¹⁶
.5012	2.15 x10 ⁻¹⁶	.3981	3.40 x10 ⁻¹⁶
.6310	1.90 x10 ⁻¹⁶	.5012	3.00 x10 ⁻¹⁶
.7943	1.60 x10 ⁻¹⁶	.6310	2.63 x10 ⁻¹⁶
1.00	1.30 x10 ⁻¹⁶	.7943	2.30 x10 ⁻¹⁶
1.40	1.01 x10 ⁻¹⁶	1.00	2.01 x10 ⁻¹⁶
1.80	8.41 x10 ⁻¹⁷	1.4	1.56 x10 ⁻¹⁶
2.5	6.57 x10 ⁻¹⁷	1.8	1.30 x10 ⁻¹⁶
3.5	5.02 x10 ⁻¹⁷	2.5	1.02 x10 ⁻¹⁶
4.5	4.09 x10 ⁻¹⁷	3.5	7.78 x10 ⁻¹⁷
5.5	3.51 x10 ⁻¹⁷	4.5	6.37 x10 ⁻¹⁷
7.0	2.89 x10 ⁻¹⁷	5.5	5.45 x10 ⁻¹⁷
9.0	2.36 x10 ⁻¹⁷	7.0	4.48 x10 ⁻¹⁷
12.0	1.87 x10 ⁻¹⁷	9.0	3.66 x10 ⁻¹⁷
14.0	1.65 x10 ⁻¹⁷	12.0	2.89 x10 ⁻¹⁷
18.0	1.36 x10 ⁻¹⁷	16.0	2.31 x10 ⁻¹⁷
20.0	1.24 x10 ⁻¹⁷	20.0	1.97 x10 ⁻¹⁷

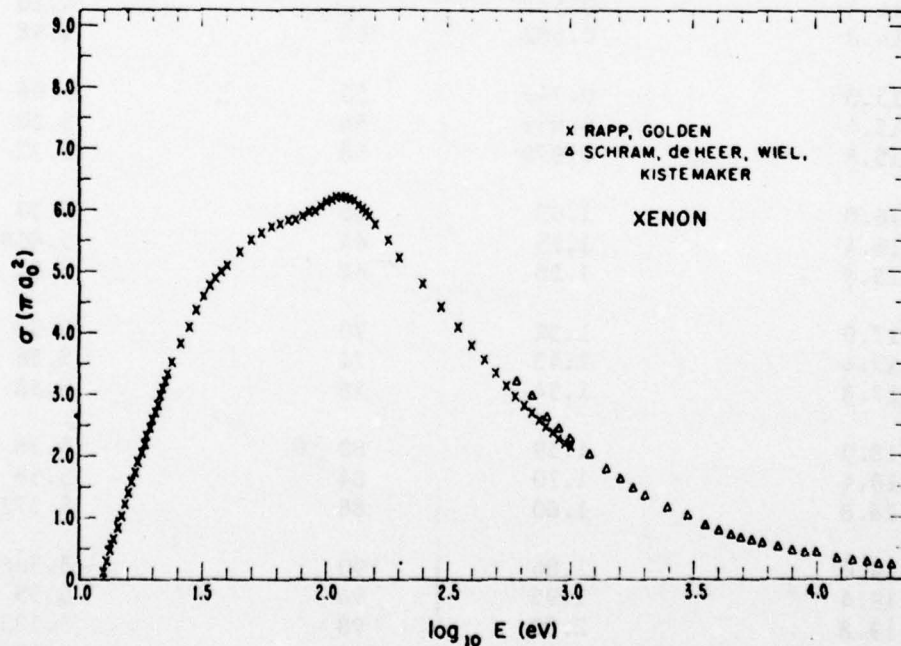
References: D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965).
B.L. Schram, F.J. De Heer, M.J. van der Wiel, and J.
Kistemaker, Physica 31, 94 (1964).

(This reference applies to Graphical Data C-4.54 also)



Total cross sections for the ionization of atomic krypton.

Figures and Graphs from review by
Kieffer and Dunn (1966).



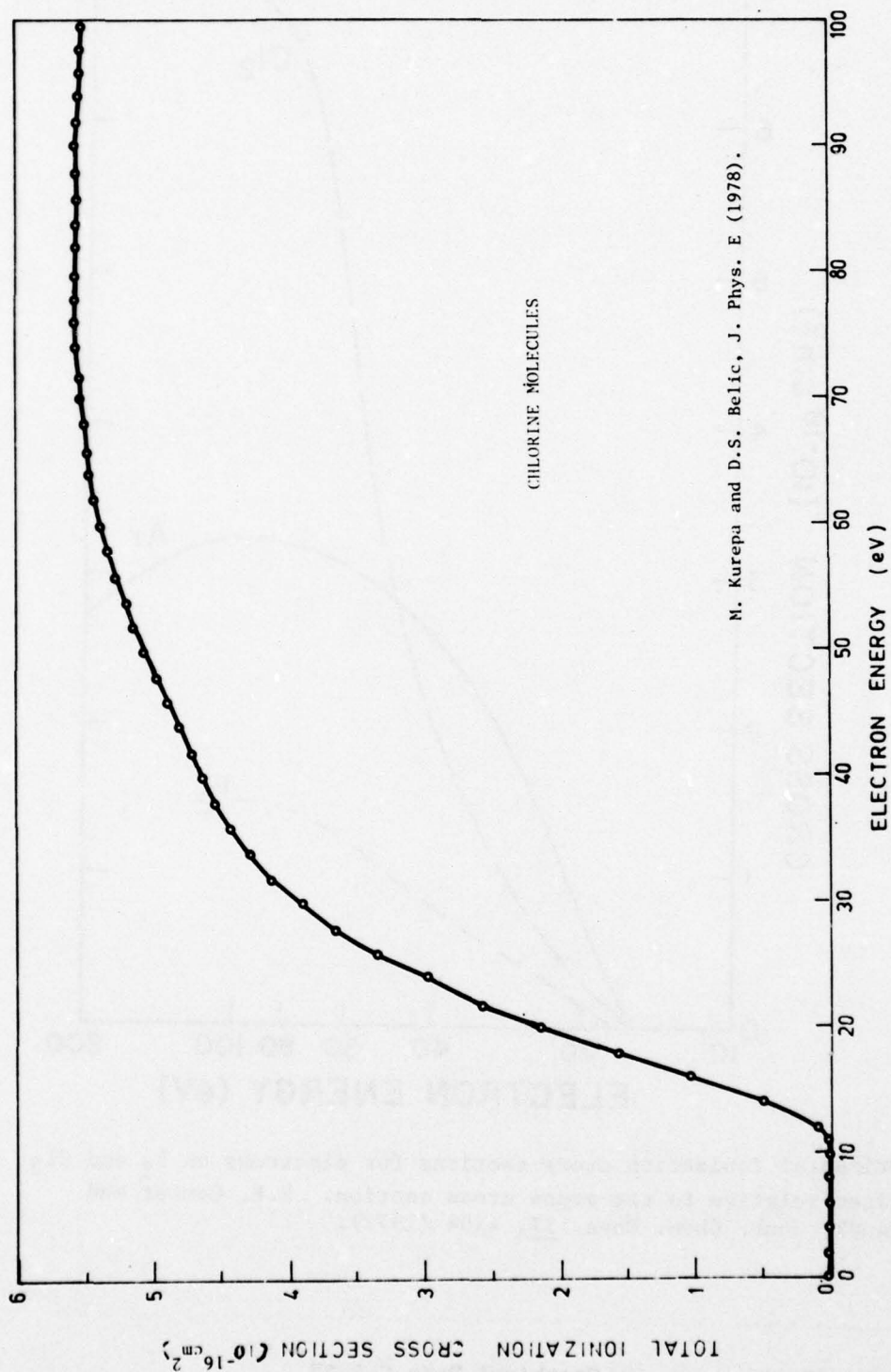
Graphical Data C-4.54.

Total cross sections for the ionization of atomic xenon

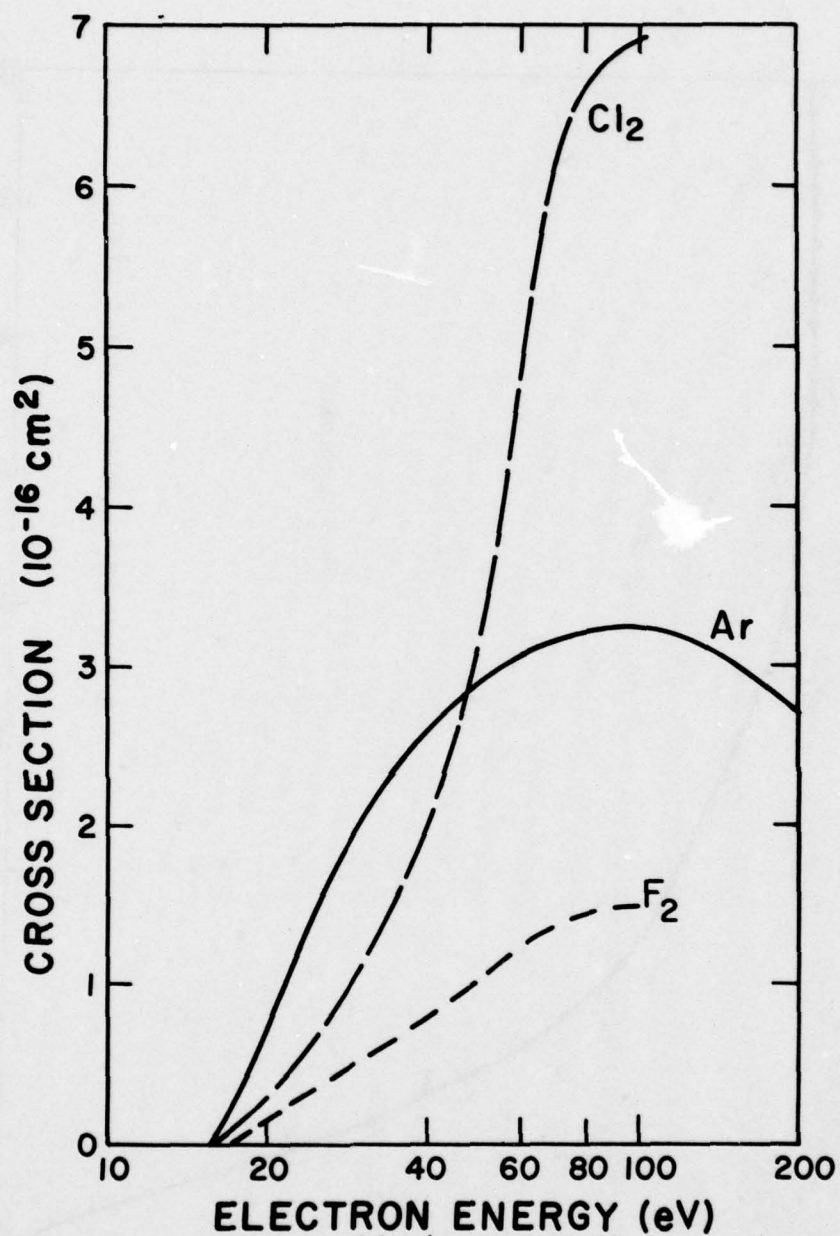
Tabular Data C-4.55.
 Experimental Cross Section for Ionization of Cl₂
 Molecules by Electron Impact
 (in units of 10^{-16} cm^2).
 The relative error is ± 0.20

Electron energy eV	cross section	Electron energy eV	cross section
11.0	0	20	2.12
11.2	0.016	21	2.38
11.4	0.028	22	2.56
11.6	0.050	23	2.79
12.0	0.0927	25	3.18
12.4	0.146	27	3.51
12.8	0.192	29	3.79
13.0	0.231	30	3.90
13.4	0.317	34	4.27
13.8	0.414	38	4.53
14.0	0.463	40	4.61
14.4	0.581	44	4.80
14.8	0.682	48	4.98
15.0	0.747	50	5.06
15.4	0.859	54	5.20
15.8	0.979	58	5.32
16.0	1.03	60	5.39
16.4	1.15	64	5.468
16.8	1.26	68	5.52
17.0	1.32	70	5.53
17.4	1.43	74	5.56
17.8	1.54	78	5.58
18.0	1.59	80	5.58
18.4	1.70	84	5.58
18.8	1.80	88	5.572
19.0	1.86	90	5.568
19.4	1.95	94	5.55
19.8	2.07	98	5.535
		100	5.524

M. Kurepa and D. S. Belic, J. Phys. E (1978).

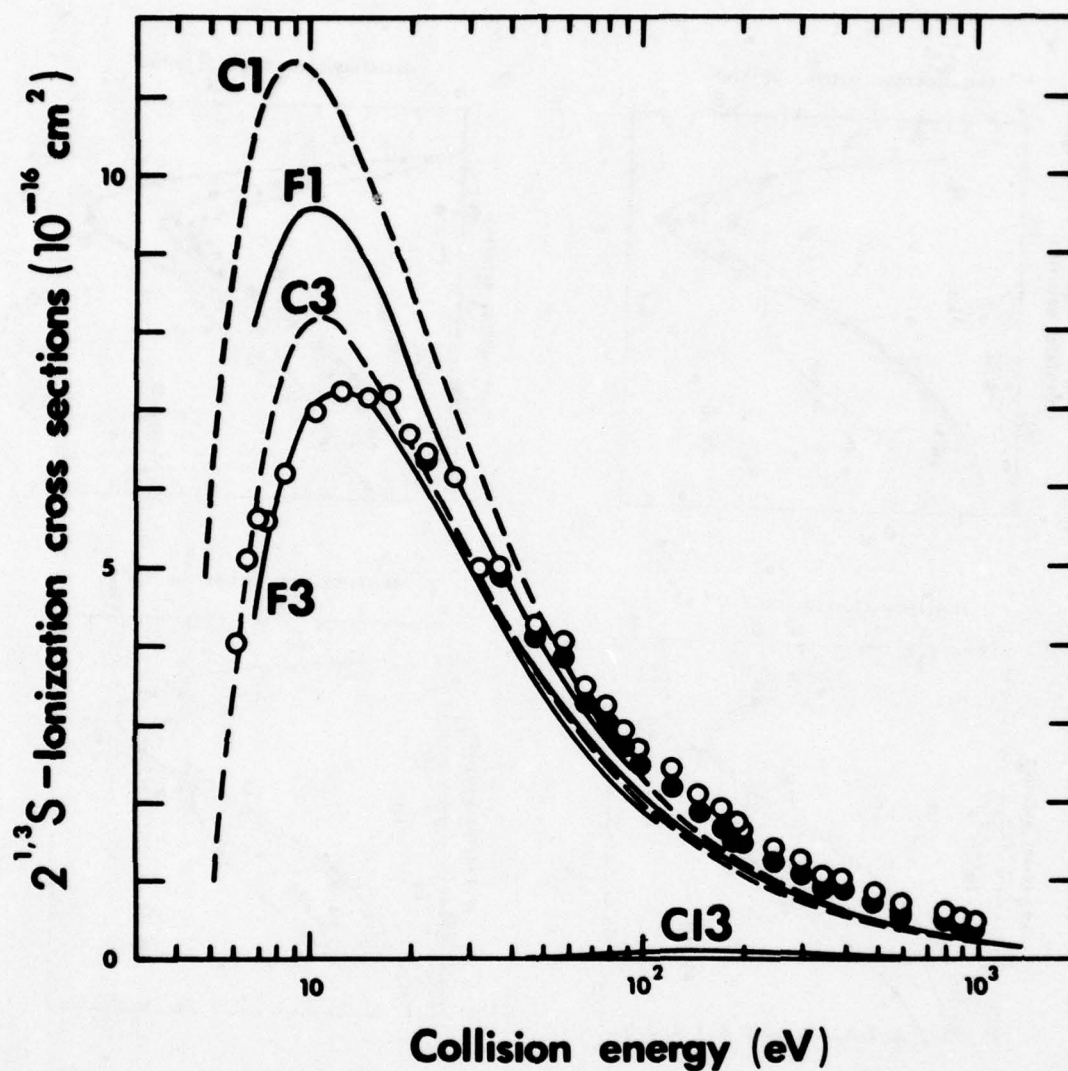


Graphical Data C-4.56.



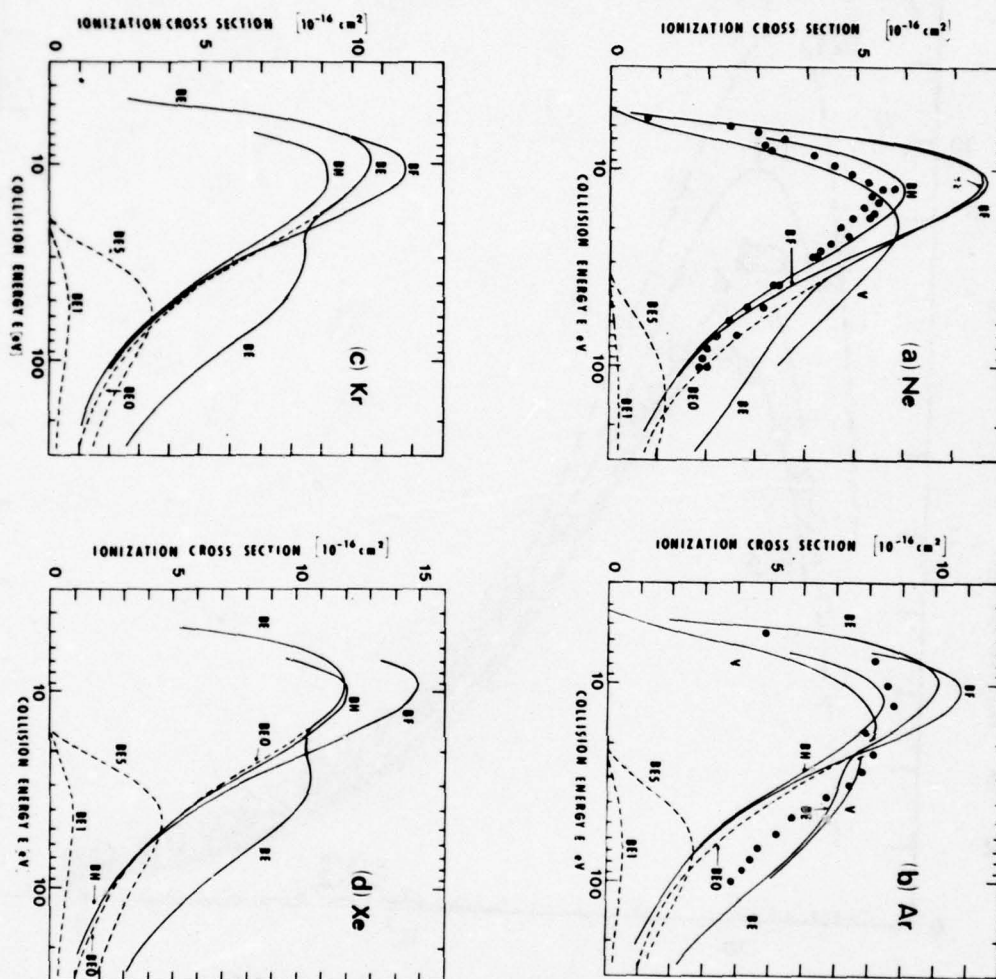
Experimental ionization cross sections for electrons on F_2 and Cl_2 obtained relative to the argon cross section. R.E. Center and A. Mandl, Jour. Chem. Phys. 57, 4104 (1972).

Graphical Data C-4.57.



Cross sections for electron impact ionization of $\text{He}(2^{1,3}\text{S})$. Curves F and C are the full-range Born and binary-encounter treatments respectively. Numerals 1 and 3 refer to 2^1S and 2^3S targets respectively. CI3 denotes the binary-encounter treatment of inner-shell ionization of $\text{He}(2^3\text{S})$ and the C3 full curve includes this contribution. The circles are experimental data of A. J. Dixon, M. F. A. Harrison, and A. C. H. Smith, *J. Phys. B* **9**, 2617 (1976). This graph is from the theoretical paper by D. Ton-That, S. T. Manson, and M. R. Flannery, *J. Phys. B* **10**, 621 (1977).

Graphical Data C-4.58.



Cross sections for electron impact ionization of metastable (a) Ne^* , (b) Ar^* , (c) Kr^* and (d) Xe^* by electrons with impact energy $E(\text{eV})$. BF and BH are Born results for outer-shell ionization obtained from integrations over the full and lower-half ranges of energy of the ejected electron. The binary encounter (quantal distribution) cross sections are denoted by BE0 for outer-shell ionization, by BE1 for ionization of one of the electrons in the np^5 shell, by BE5 for the total ionization of the np^5 shell, and by BE for the sum of BE0 and BE5. Binary encounter (exponential distribution) results of Vriens are represented by V. The dots are experimental data of Dixon, Harrison and Smith. These graphs are from the theoretical paper by D. Ton-That and M. R. Flannery, Phys. Rev. A 15, 517 (1977).

C-5. ELECTRON-ION RECOMBINATION

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- D C.F. Barnett, J.A. Ray, E. Ricci, I. Wilker, E.W. McDaniel, E.W. Thomas, and H.B. Gilbody, "Atomic Data for Controlled Fusion Research," Controlled Fusion Atomic Data Center. Oak Ridge National Laboratory, Oak Ridge, Tennessee (Feb 1977). Reports ORNL 5206 and 5207, 680 pages.
- D.R. Bates and A. Dalgarno, "Electronic Recombination," in D.R. Bates (Ed.), "Atomic and Molecular Processes," pg. 245, Academic, N. Y. (1962).
- D M.A. Biondi, "Recombination," in G. Bekefi (Ed.), "Principles of Laser Plasmas," pg. 126, Wiley, N. Y. (1976).
- D,R M.J. Seaton and P.J. Storey, "Di-electronic Recombination," in P.G. Burke and B.L. Moiseiwitsch (Eds.) "Atomic Processes and Applications," pg. 133, North-Holland, Amsterdam (1976).

C-5. ELECTRON-ION RECOMBINATION

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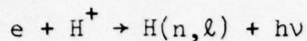
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Calculated Recombination Coefficient $\alpha_{n,\ell}$ for the
Radiative Recombination of Electrons to H^+ Ions in Different Final
Quantum States n,ℓ at Temperatures T of 10,000°K and 20,000°K



Recombination Coefficient $\alpha_{n,\ell}$ (10^{-16} cm³/sec)

$n \backslash \ell$	$T = 10,000^\circ K$											
	0	1	2	3	4	5	6	7	8	9	10	11
1	1582											
2	234	536										
3	78.2	204	173									
4	36.3	96.5	109	55.5								
5	19.9	52.8	66.9	49.4	17.9							
6	12.2	31.6	42.9	37.5	20.5	5.85						
7	7.94	20.3	28.8	28.2	18.7	8.22	2.00					
8	5.48	13.7	20.0	20.9	15.8	8.59	3.25	0.706				
9	3.94	9.73	14.4	15.6	12.8	7.97	3.75	1.28	0.259			
10	2.93	7.09	10.6	12.0	10.5	7.12	3.83	1.61	0.502	0.100		
11	2.23	5.34	7.94	9.15	8.45	6.20	3.67	1.77	0.688	0.203	0.039	
12	1.74	3.99	6.08	7.22	6.85	5.38	3.41	1.83	0.825	0.304	0.084	0.016

$n \backslash \ell$	$T = 20,000^\circ K$											
	0	1	2	3	4	5	6	7	8	9	10	11
1	1079											
2	160	324										
3	52.9	123	90.9									
4	24.3	58.1	56.7	25.7								
5	13.2	31.3	34.9	22.3	7.54							
6	7.95	18.6	22.3	16.9	8.10	2.35						
7	5.14	11.7	15.1	12.7	7.38	2.96	0.766					
8	3.52	7.81	10.5	9.78	6.43	3.11	1.10	0.267				
9	2.50	5.45	7.51	7.45	5.45	3.00	1.28	0.424	0.096			
10	1.86	3.94	5.50	5.74	4.53	2.74	1.32	0.526	0.164	0.036		
11	1.40	2.93	4.13	4.49	3.75	2.46	1.29	0.572	0.215	0.064	0.014	
12	1.09	2.23	3.16	3.51	3.08	2.17	1.24	0.598	0.252	0.091	0.026	0.006

Reference:

D.R. Bates, Case Studies in Atomic Physics 4, 57 (1974).

Tabular Data C-5.2.

- (a) Total Recombination Coefficient α for the Radiative Electron-Ion Recombination of Various Ions at 250°K

System	Recombination Coefficient α (cm ³ /sec)
H ⁺ + e	4.8 E-12
He ⁺ + e	4.8 E-12
C ⁺ + e	4.2 E-12
N ⁺ + e	3.6 E-12
O ⁺ + e	3.7 E-12

Reference:

D.R. Bates and A. Dalgarno, Atomic and Molecular Processes, ed. by D.R. Bates, Academic Press, New York, 1962, p. 252.

- (b) Recombination Coefficient α for the Radiative Recombination of Electrons with He⁺ and H⁺ Ions at 10,000°K and 20,000°K

Recombination Coefficient α (cm ³ /sec)					
Level Formed	He Ground State	Excited He Singlets	Excited He Triplets	He Any Level	H Any Level
Temp. (°K)					
10,000	1.59 E-13	6.30 E-14	2.10 E-13	4.31 E-13	4.17 E-13
20,000	1.15 E-13	3.50 E-14	1.20 E-13	2.69 E-13	2.51 E-13

Reference:

A. Burgess and M.F. Seaton, Monthly Notices of the Royal Astronomical Society 121, 471 (1960).

- (c) Calculated Radiative Recombination Coefficient α for the Recombination of Electrons with O⁺ Ions
e + O⁺ → O + hν

Electron Temp. (°K)	Recombination Coefficient α (cm ³ /sec)
2.5 E 02	3.4 E-12
5.0 E 02	2.2 E-12
1.0 E 03	1.3 E-12
2.0 E 03	8.0 E-13

Reference:

A. Dalgarno, Ann. Geophys. 17, 16 (1961).

- (a) **Tabular Data C-5.3.**
 Calculated Recombination Coefficient $\alpha_{n,l}$ for the Radiative Recombination of Electrons to H^+ Ions in Several Final Quantum States at Various Temperatures T $e + H^+ \rightarrow H(n,l) + h\nu$

Quantum Numbers of Final States		Recombination Coefficient $\alpha_{n,l}$ (cm^3/sec)				
n	l	T=312.5 °K	T=1250 °K	T=10 ⁴ °K	T=8x10 ⁴ °K	T=6.4x10 ⁵ °K
2	0	1.36 E-12	6.8 E-13	2.3 E-13	6.7 E-14	1.1 E-14
	1	3.72 E-12	1.82 E-12	5.4 E-13	9.4 E-14	8.0 E-15
3	0	4.60 E-13	2.3 E-13	8.0 E-14	2.1 E-14	3.0 E-15
	1	1.41 E-12	6.9 E-13	2.0 E-13	3.5 E-14	3.0 E-15
	2	1.61 E-12	7.5 E-13	1.7 E-13	1.9 E-14	1.0 E-15

Reference:

H.S.W. Massey, Electronic and Ionic Impact Phenomena, Vol. II, Electron Collisions with Molecules and Photo-Ionization, p. 1070 (Clarendon Press, Oxford, 1969).

- (b)
 Calculated Cross Sections for the Radiative Recombination of Electrons to H^+ Ions in Various Final Quantum States for Four Different Electron Energies $e + H^+ \rightarrow H(n,l) + h\nu$

Quantum Numbers of Final States		Cross Sections (cm^2)			
n	l	0.28 eV	0.13 eV	0.069 eV	0.034 eV
2	0	1.20 E-21	2.45 E-21	4.80 E-21	9.81 E-21
	1	3.04 E-21	6.48 E-21	1.29 E-20	2.67 E-20
3	0	4.02 E-22	8.26 E-22	1.62 E-21	3.30 E-21
	1	1.15 E-21	2.46 E-21	4.95 E-21	1.01 E-20
	2	1.15 E-21	2.62 E-21	5.47 E-21	1.15 E-20

Reference:

H.S. W. Massey, Electronic and Ionic Impact Phenomena, Vol. II, Electron Collisions with Molecules and Photo-Ionization, Clarendon Press, Oxford (1969), p. 1070.

Tabular Data C-5.4.

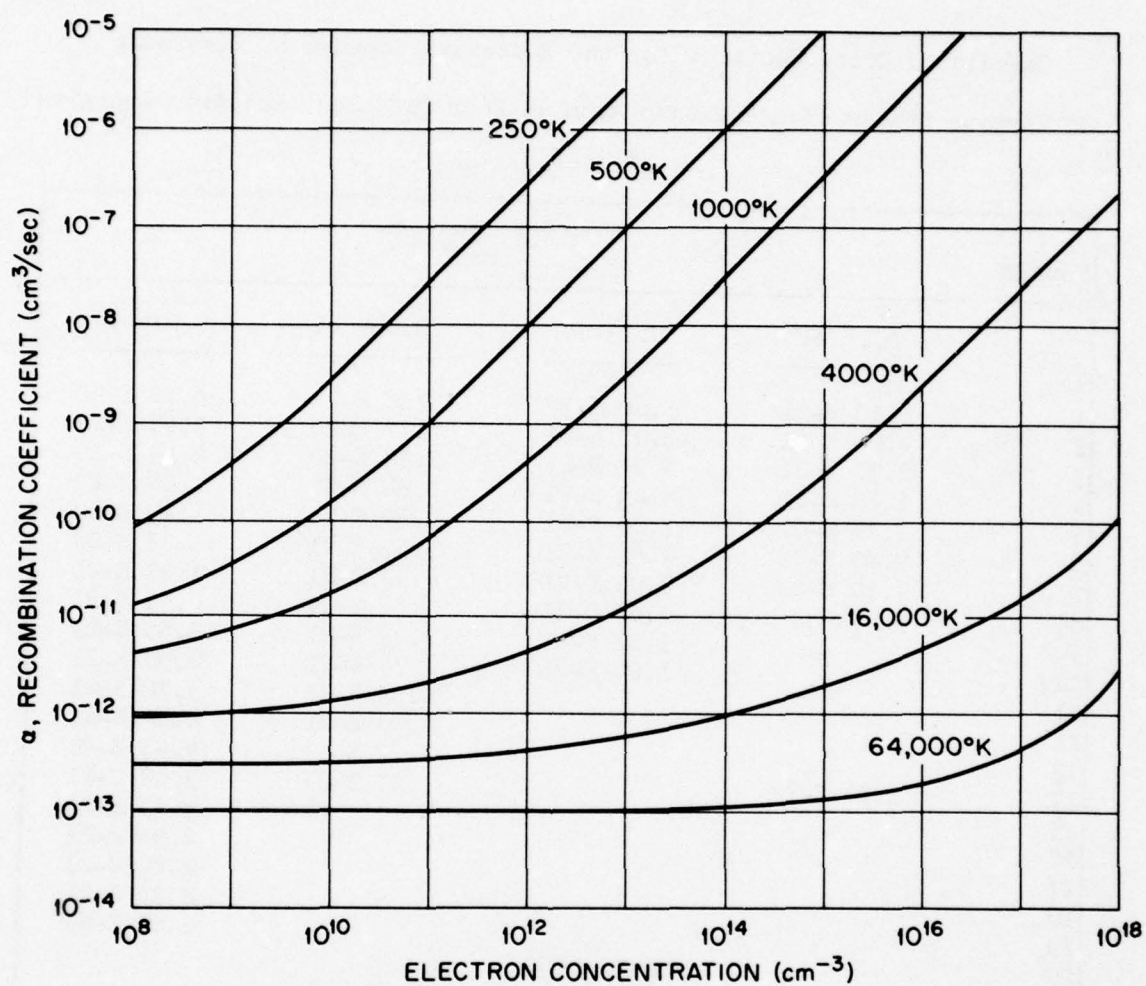
Calculated Recombination Coefficient α for the Collisional-Radiative Recombination of Electrons with

H^+ Ions in an Optically Thin H^+ Plasma, for Various Electron Temperatures T_e

Electron Concentration n_e (cm ⁻³)	Recombination Coefficient α (cm ³ /sec)					
	$T_e = 250^\circ$ K	$T_e = 500^\circ$ K	$T_e = 1000^\circ$ K	$T_e = 4000^\circ$ K	$T_e = 16,000^\circ$ K	$T_e = 64,000^\circ$ K
Limit $n_e \rightarrow 0$	4.8 E-12	3.1 E-12	2.0 E-12	7.9 E-13	2.9 E-13	1.0 E-13
1.0 E 08	8.8 E-11	1.4 E-11	4.1 E-12	9.2 E-13	3.0 E-13	1.0 E-13
1.0 E 09	4.0 E-10	3.8 E-11	7.5 E-12	1.0 E-12	3.0 E-13	1.0 E-13
1.0 E 10	2.8 E-09	1.6 E-10	1.9 E-11	1.4 E-12	3.2 E-13	1.0 E-13
1.0 E 11	2.7 E-08	1.0 E-09	6.9 E-11	2.2 E-12	3.4 E-13	1.0 E-13
1.0 E 12	2.6 E-07	9.0 E-09	3.9 E-10	4.4 E-12	4.3 E-13	1.0 E-13
1.0 E 13	2.6 E-06	8.9 E-08	3.1 E-09	1.2 E-11	6.2 E-13	1.1 E-13
1.0 E 14	2.6 E-05	8.8 E-07	2.9 E-09	5.1 E-11	1.0 E-12	1.2 E-13
1.0 E 15		8.8 E-06	2.9 E-07	2.7 E-10	2.3 E-12	1.6 E-13
1.0 E 16			2.9 E-06	2.3 E-09	5.0 E-12	1.9 E-13
1.0 E 17				2.1 E-08	1.4 E-11	4.4 E-13
1.0 E 18				2.0 E-07	9.6 E-11	2.8 E-12
Limit $n_e \rightarrow \infty$	2.6 E-19 n_e	8.8 E-21 n_e	2.9 E-22 n_e	1.9 E-25 n_e	9.1 E-29 n_e	2.7 E-30 n_e

Reference:

D.R. Bates, A.E. Kingston, and R.W.P. McWhirter, Proc. Roy. Soc. (London) A267, 297 (1962).

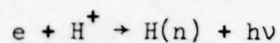


Calculated recombination coefficient α for the collision-radiative recombination of electrons with H^+ ions in an optically thin H^+ plasma, for various electron temperatures T_e .

Graphical Data C-5.5.

Tabular Data C-5.6.

Calculated Cross Sections for the Radiative Capture of Electrons
to Various States of a Hydrogen Atom at Four Different Electron Energies

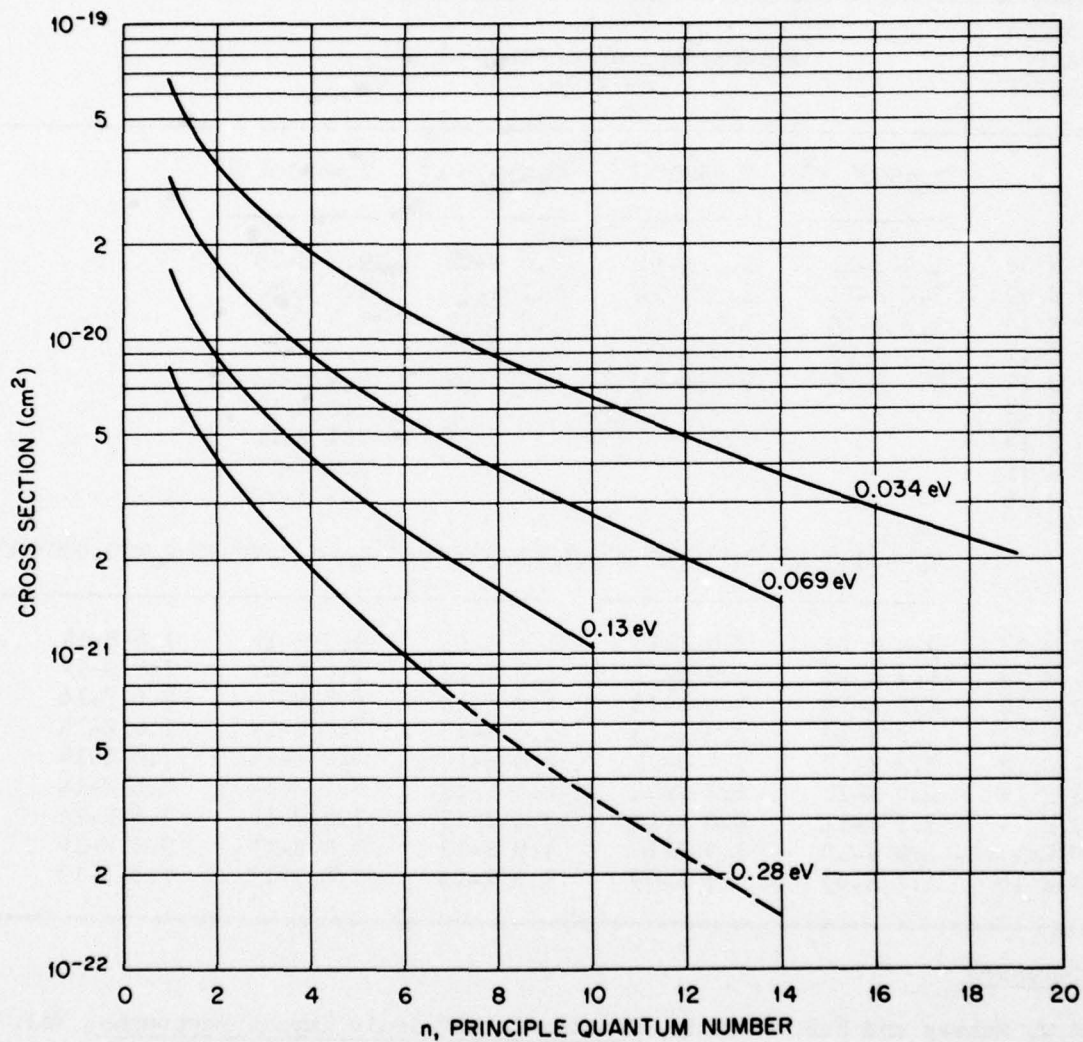


Total*	Cross Sections (cm ²)			
	0.28 eV	0.13 eV	0.069 eV	0.034 eV
1	8.10 E-21	1.66 E-20	3.28 E-20	6.70 E-20
2	4.24 E-21	8.93 E-21	1.77 E-20	3.65 E-20
3	2.70 E-21	5.91 E-21	1.20 E-20	2.49 E-20
4	1.88 E-21	4.24 E-21	8.84 E-21	1.86 E-20
5	1.36 E-21	3.20 E-21	6.89 E-21	1.49 E-20
6	9.90 E-22	2.49 E-21	5.51 E-21	1.23 E-20
7	7.30 E-22	2.00 E-21	4.52 E-21	1.03 E-20
8		1.62 E-21	3.81 E-21	8.75 E-21
9		1.31 E-21	3.23 E-21	7.55 E-21
10		1.04 E-21	2.74 E-21	6.50 E-21
11			2.33 E-21	5.72 E-21
12			2.00 E-21	4.52 E-21
13			1.72 E-21	4.03 E-21
14	1.50 E-22		1.47 E-21	3.62 E-21
15				3.25 E-21
16				2.91 E-21
17				2.62 E-21
18				2.35 E-21
19				2.09 E-21
20		2.15 E-22		
28			3.02 E-22	
40				4.32 E-22
Total	2.30 E-20	5.37 E-20	1.19 E-19	2.72 E-19

Reference:

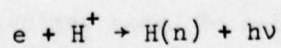
H.S.W. Massey, Electronic and Ionic Impact Phenomena, Vol. II, Electron Collisions with Molecules and Photo-Ionization, Clarendon Press, Oxford (1969), p. 1071.

* Total Quantum Number of Atomic State into which Electron is Captured.



Graphical Data C-5.7.

Calculated Cross Sections for the Radiative Capture of Electrons
to Various States of a Hydrogen Atom at Four Different Electron Energies



Tabular Data C-5.8.

Calculated Recombination Coefficient α for the Collisional-Radiative Recombination of Electrons with H^+ Ions in Three Different H^+ Plasmas (Optically Thin, Optically Thick Towards Lines of the Lyman Series, and Optically Thick Towards Lines of all Series) for Several Electron Temperatures T_e

Electron Density n_e (cm^{-3})	Recombination Coefficient α (cm^3/sec)					
	$T_e=500^\circ K^*$	$T_e=500^\circ K^\dagger$	$T_e=500^\circ K^\ddagger$	$T_e=4000^\circ K^*$		
1.0 E 08	1.4 E-11	1.1 E-11	2.6 E-12	9.2 E-13		
1.0 E 09	3.8 E-11	3.3 E-11	1.1 E-11	1.0 E-12		
1.0 E 10	1.6 E-10	1.6 E-10	1.0 E-10	1.4 E-12		
1.0 E 11	1.0 E-09	1.0 E-09	1.0 E-09	2.2 E-12		
1.0 E 12	9.0 E-09	9.0 E-09	9.0 E-09	4.4 E-12		
1.0 E 13				1.2 E-11		
1.0 E 14				5.1 E-11		
1.0 E 15				2.7 E-10		
1.0 E 16				2.3 E-09		
	$T_e=4000^\circ K^\dagger$	$T_e=4000^\circ K^\ddagger$	$T_e=32,000^\circ K^*$	$T_e=32,000^\circ K^\dagger$	$T_e=32,000^\circ K^\ddagger$	
1.0 E 08	9.2 E-13	3.9 E-13	1.8 E-13	9.5 E-14	7.6 E-14	
1.0 E 09	1.0 E-12	3.9 E-13	1.8 E-13	9.0 E-14	7.6 E-14	
1.0 E 10	1.2 E-12	3.9 E-13	1.8 E-13	8.8 E-14	7.6 E-14	
1.0 E 11	2.0 E-12	3.9 E-13	1.8 E-13	8.5 E-14	7.6 E-14	
1.0 E 12	3.3 E-12	5.4 E-13	2.0 E-13	8.2 E-14	7.6 E-14	
1.0 E 13	9.0 E-12	2.4 E-12	2.4 E-13	8.0 E-14	7.6 E-14	
1.0 E 14	3.5 E-11	2.0 E-11	3.1 E-13	7.6 E-14	7.6 E-14	
1.0 E 15	1.9 E-10	1.9 E-10	4.9 E-13	9.0 E-14	9.0 E-14	
1.0 E 16	1.7 E-09	1.7 E-09	7.3 E-13	1.8 E-13	1.8 E-13	

Reference:

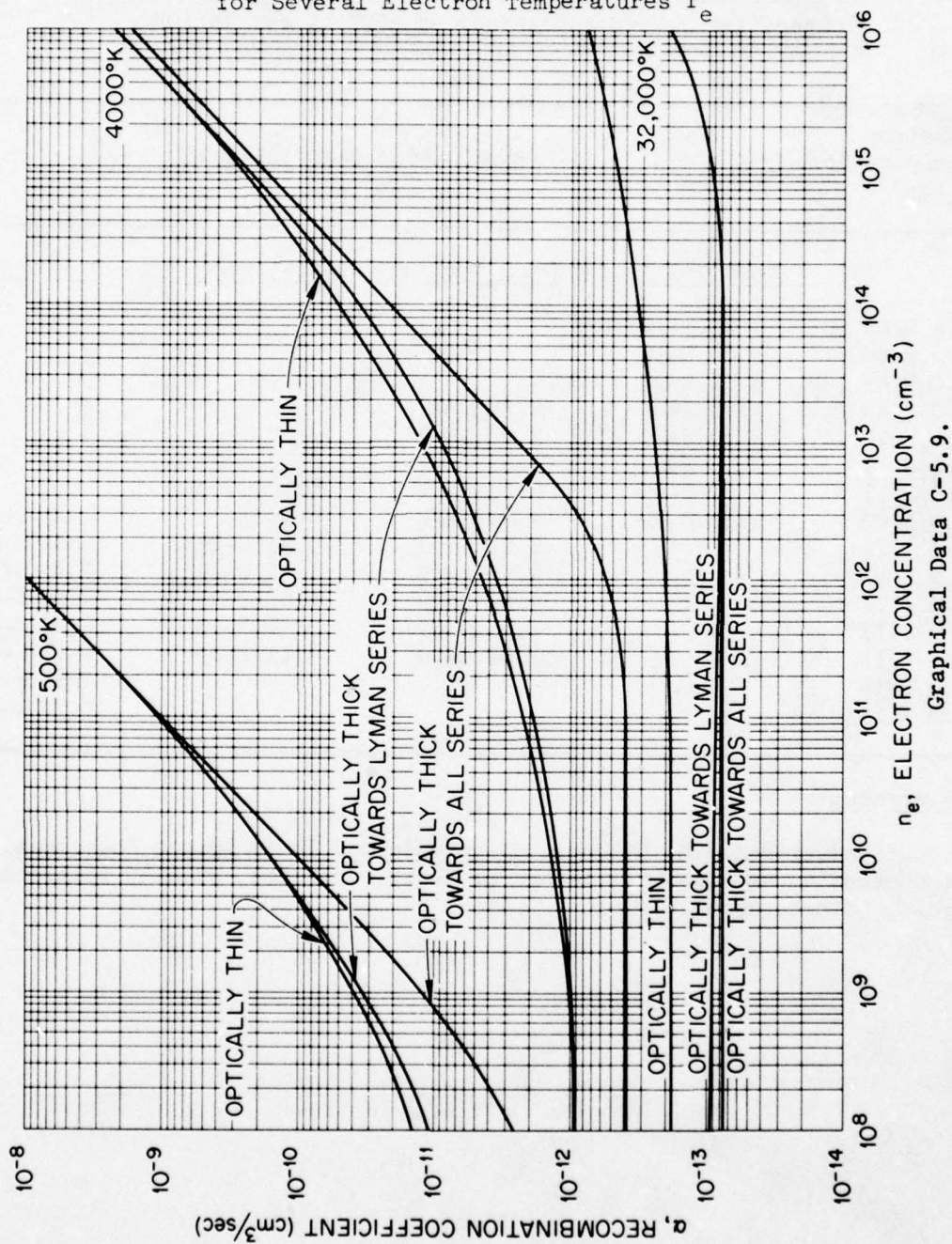
H.S.W. Massey and H.B. Gilbody, Electronic and Ionic Impact Phenomena, Vol. IV, Recombination and Fast Collisions of Heavy Particles, p. 2135 (Clarendon Press, Oxford, 1974).

* Optically thin.

† Optically thick towards lines of Lyman series.

‡ Optically thick towards lines of all series.

Calculated Recombination Coefficient α for the Collisional-Radiative
 Recombination of Electrons with H^+ Ions in Three Different
 H^+ Plasmas (Optically Thin, Optically Thick Towards Lines
 of the Lyman Series, and Optically Thick Towards Lines of all Series)
 for Several Electron Temperatures T_e



Graphical Data C-5.9.

Tabular Data C-5.10.

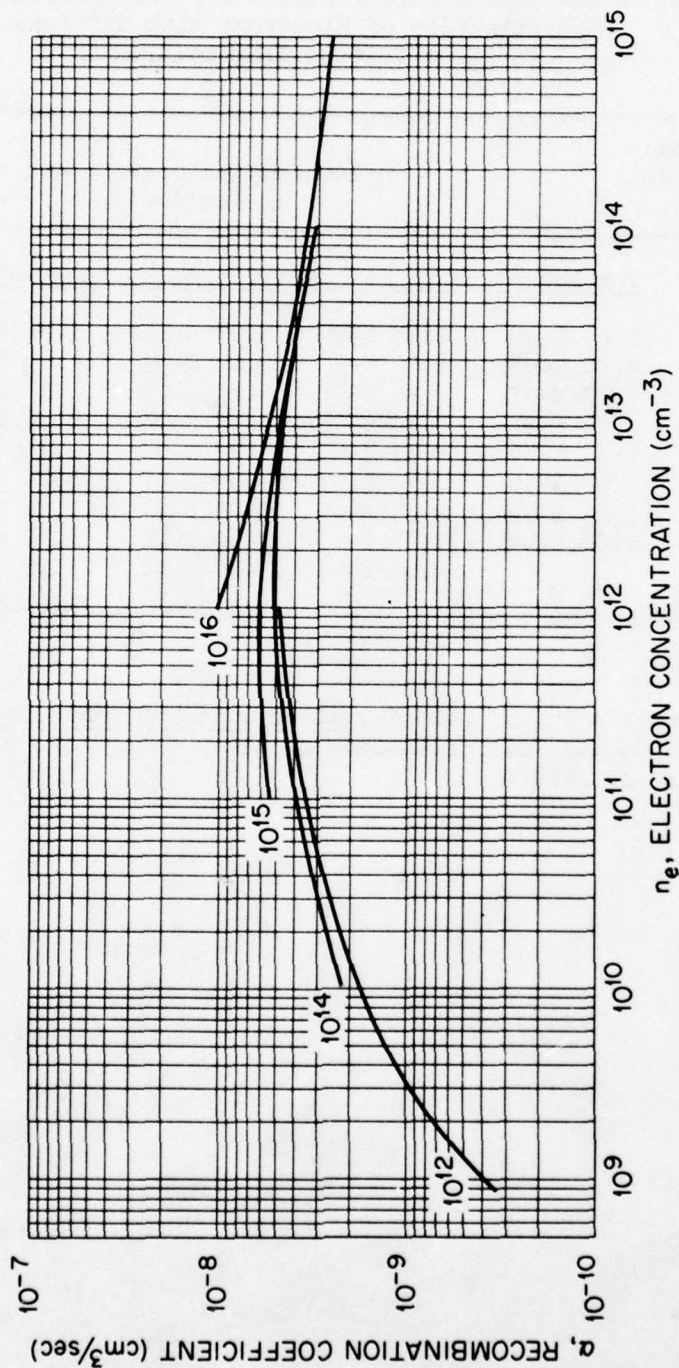
Calculated Recombination Coefficient α for the Collisional-Radiative Recombination of Electrons with H^+ Ions in an H^+ Plasma in Which Both the Neutral Gas Temperature T_g and the Ion Temperature T_i are Maintained at $250^\circ K$, for Various Concentrations N of Neutral Atoms in the Ground State

Electron Concentration $n_e (cm^{-3})$	Recombination Coefficient α (cm^3/sec)			
	$N=10^{12} cm^{-3}$	$N=10^{14} cm^{-3}$	$N=10^{15} cm^{-3}$	$N=10^{16} cm^{-3}$
8.6 E 08	3.34 E-10			
1.0 E 09	3.80 E-10			
3.0 E 09	9.71 E-10			
1.0 E 10	1.78 E-09	2.24 E-09		
3.0 E 10	2.50 E-09	2.97 E-09		
1.0 E 11	3.53 E-09	3.83 E-09	5.33 E-09	
5.1 E 11	4.50 E-09	4.85 E-09	6.10 E-09	
1.0 E 12	4.81 E-09	4.89 E-09	6.00 E-09	1.00 E-08
1.3 E 12		5.04 E-09	5.95 E-09	9.20 E-09
3.0 E 12		4.90 E-09	5.45 E-09	7.30 E-09
1.0 E 13		4.49 E-09	4.55 E-09	5.33 E-09
3.0 E 13		3.65 E-09	3.65 E-09	4.15 E-09
1.0 E 14		3.02 E-09	3.11 E-09	3.27 E-09
3.0 E 14				2.88 E-09
1.0 E 15				2.50 E-09

Reference:

H.S.W. Massey and H.B. Gilbody, Electronic and Ionic Impact Phenomena, Vol. IV, Recombination and Fast Collisions of Heavy Particles, p. 2145 (Clarendon Press, Oxford, 1974).

Calculated Recombination Coefficient α for the Collisional-Radiative
 Recombination of Electrons with H^+ Ions in an H^+ Plasma
 in Which Both the Neutral Gas Temperature T_g and the Ion
 Temperature T_i are Maintained at $250^\circ K$, for Various
 Concentrations N of Neutral Atoms in the Ground State



Graphical Data C-5.11.

Tabular Data C-5.12.

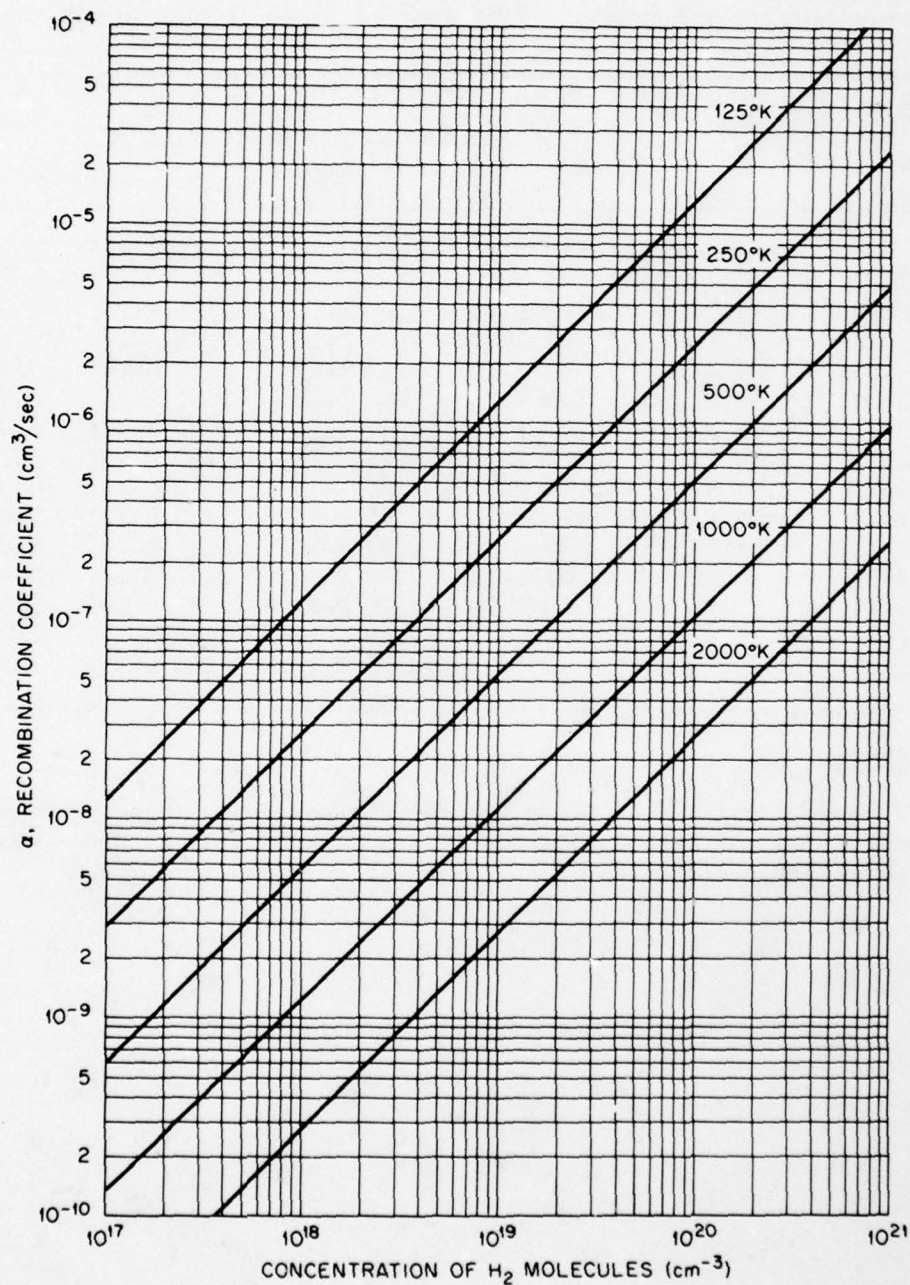
Calculated Recombination Coefficient α for the Collisional-Radiative
Recombination of Electrons with H_2^+ Ions
in H_2 at Various Temperatures T

Concentration of H_2 Molecules (cm^{-3})	Recombination Coefficient α (cm^3/sec)				
	T = 125 °K	T = 250 °K	T = 500 °K	T = 1000° K	T = 2000 °K
1.0 E 17	1.27 E-08	2.91 E-09	5.97 E-10	1.37 E-10	
3.6 E 17	4.20 E-08	1.00 E-08	2.10 E-09	4.60 E-10	1.00 E-10
1.0 E 18	1.30 E-07	2.76 E-08	5.52 E-09	1.21 E-09	2.73 E-10
3.0 E 18	3.80 E-07	8.10 E-08	1.65 E-08	3.70 E-09	8.10 E-10
1.0 E 19	1.30 E-06	2.57 E-07	5.22 E-08	1.14 E-08	2.61 E-09
3.0 E 19	3.90 E-06	7.70 E-07	1.58 E-07	3.25 E-08	7.90 E-09
1.0 E 20	1.27 E-05	2.37 E-06	5.05 E-07	1.06 E-07	2.48 E-08
7.1 E 20	1.00 E-04	1.75 E-05	3.50 E-06	7.10 E-07	1.82 E-07
1.0 E 21		2.51 E-05	5.00 E-06	1.00 E-06	2.57 E-07

Reference:

H.S.W. Massey and H.B. Gilbody, Electronic and Ionic Impact Phenomena, Vol. IV, Recombination and Fast Collisions of Heavy Particles, p. 2153 (Clarendon Press, Oxford, 1974).

Calculated Recombination Coefficient α for the Collisional-Radiative
Recombination of Electrons with H_2^+ Ions
in H_2 at Various Temperatures T



Graphical Data C-5.13.

Tabular Data C-5.14.

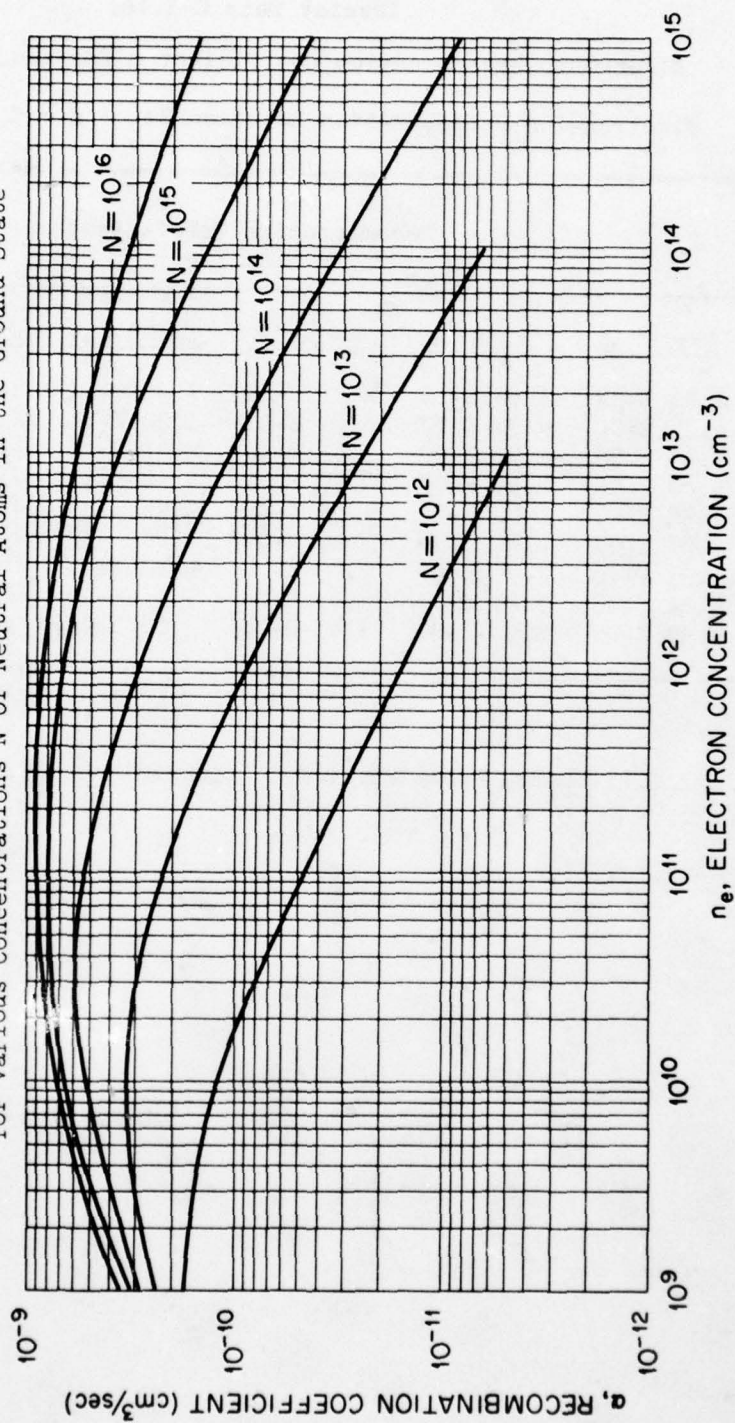
Calculated Recombination Coefficient α for the Collisional-Radiative Recombination of Electrons with He^+ Ions in an Optically Thick Decaying He^+ Plasma with Atom Temperatures Maintained at 250°K for Various Concentrations N of Neutral Atoms in the Ground State

Electron Concentration $n_e (\text{cm}^{-3})$	Recombination Coefficient α (cm^3/sec)				
	$N=10^{12} \text{cm}^{-3}$	$N=10^{13} \text{cm}^{-3}$	$N=10^{14} \text{cm}^{-3}$	$N=10^{15} \text{cm}^{-3}$	$N=10^{16} \text{cm}^{-3}$
1.0 E 09	1.73 E-10	2.36 E-10	2.89 E-10	3.21 E-10	3.64 E-10
3.0 E 09	1.55 E-10	3.00 E-10	3.85 E-10	4.90 E-10	5.40 E-10
1.0 E 10	1.23 E-10	3.33 E-10	5.32 E-10	6.60 E-10	7.36 E-10
3.6 E 10	7.40 E-11	2.90 E-10	5.86 E-10	7.70 E-10	8.50 E-10
1.0 E 11	4.61 E-11	2.25 E-10	5.32 E-10	7.80 E-10	8.90 E-10
2.3 E 11	3.10 E-11	1.65 E-10	4.45 E-10	7.60 E-10	9.12 E-10
1.0 E 12	1.53 E-11	8.61 E-11	2.89 E-10	6.60 E-10	8.40 E-10
3.0 E 12	8.95 E-12	4.80 E-11	1.85 E-10	5.20 E-10	7.20 E-10
1.0 E 13	4.88 E-12	2.44 E-11	1.06 E-10	3.64 E-10	5.86 E-10
3.0 E 13		1.30 E-11	5.90 E-11	2.27 E-10	4.45 E-10
1.0 E 14		6.03 E-12	3.16 E-11	1.33 E-10	3.21 E-10
3.0 E 14			1.65 E-11	7.90 E-11	2.23 E-10
1.0 E 15			8.07 E-12	4.24 E-11	1.50 E-10

Reference:

H.S.W. Massey and H.B. Gilbody, Electronic and Ionic Impact Phenomena, Vol. IV, Recombination and Fast Collisions of Heavy Particles, p. 2147 (Clarendon Press, Oxford, 1974).

Calculated Recombination Coefficient α for the Collisional-Radiative
 Recombination of Electrons with He^+ Ions in an Optically Thick
 Decaying He^+ Plasma with Atom Temperatures Maintained at 250°K
 for Various Concentrations N of Neutral Atoms in the Ground State



Graphical Data C-5.15.

Tabular Data C-5.16.

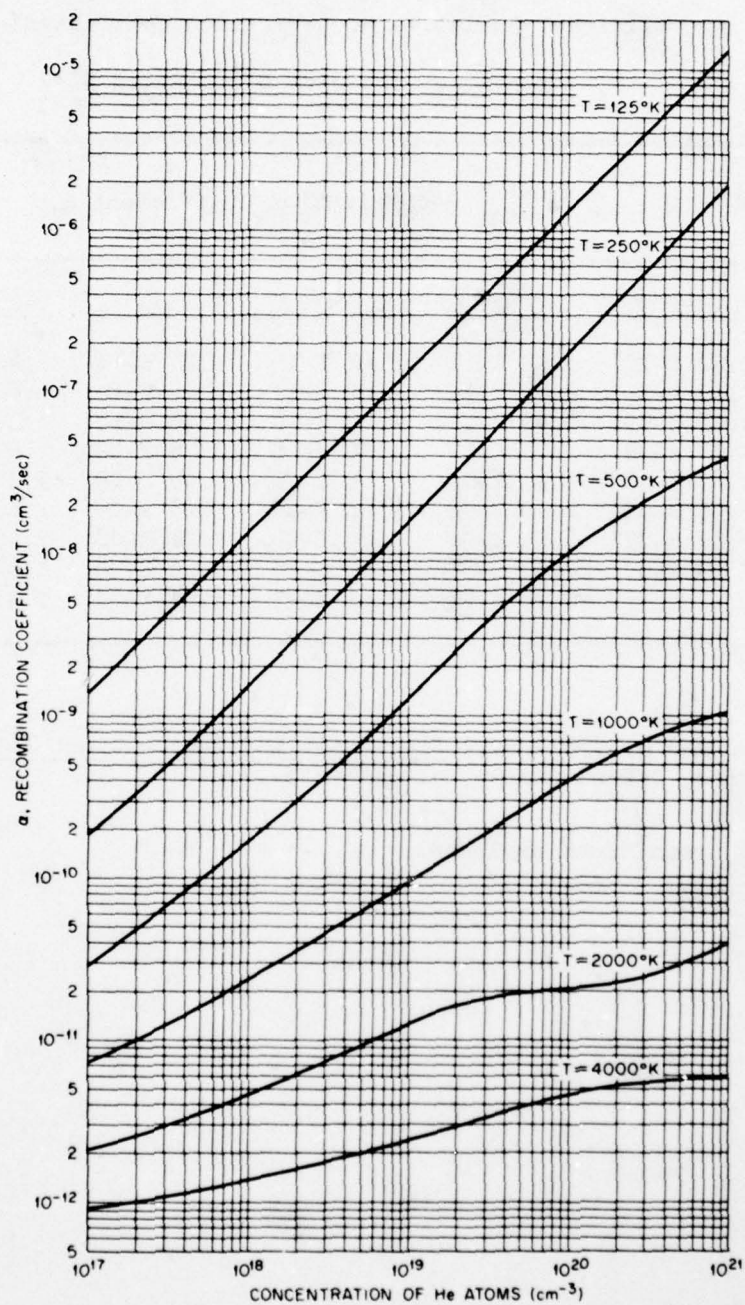
Electronic Recombination Coefficient α for the 3-Body
Electron-Ion Recombination Reaction $\text{He}^+ + e + \text{He} \rightarrow 2\text{He}$

He Atom Density (cm^{-3})	Recombination Coefficient α (cm^3/sec)					
	<u>T=125° K</u>	<u>T=250° K</u>	<u>T=500° K</u>	<u>T=1000° K</u>	<u>T=2000° K</u>	<u>T=4000° K</u>
1.0 E 17	1.41 E-09	1.82 E-10	2.88 E-11	7.30 E-12	2.09 E-12	9.00 E-13
3.0 E 17	4.15 E-09	4.93 E-10	6.52 E-11	1.22 E-11	2.94 E-12	1.10 E-12
1.0 E 18	1.34 E-08	1.52 E-09	1.67 E-10	2.37 E-11	4.63 E-12	1.40 E-12
3.0 E 18	4.00 E-08	4.59 E-09	4.26 E-10	4.54 E-11	7.16 E-12	1.77 E-12
1.0 E 19	1.33 E-07	1.52 E-08	1.30 E-09	9.44 E-11	1.27 E-11	2.40 E-12
3.0 E 19	4.00 E-07	4.86 E-08	3.40 E-09	1.95 E-10	1.77 E-11	3.24 E-12
1.0 E 20	1.33 E-06	1.79 E-07	1.00 E-08	4.13 E-10	2.04 E-11	4.63 E-12
3.0 E 20	4.11 E-06	5.45 E-07	2.09 E-08	7.11 E-10	2.50 E-11	5.45 E-12
1.0 E 21	1.30 E-05	1.90 E-06	3.88 E-08	1.08 E-09	3.88 E-11	5.78 E-12

Reference:

D.R. Bates and S.P. Khare, Proc. Phys. Soc. (London) 85, 231 (1965).

Electronic Recombination Coefficient α for the 3-Body
Electron-Ion Recombination Reaction $\text{He}^+ + e + \text{He} \rightarrow 2\text{He}$



Graphical Data C-5.17.

Tabular Data C-5.18.

Collisional-Radiative Recombination Coefficient α

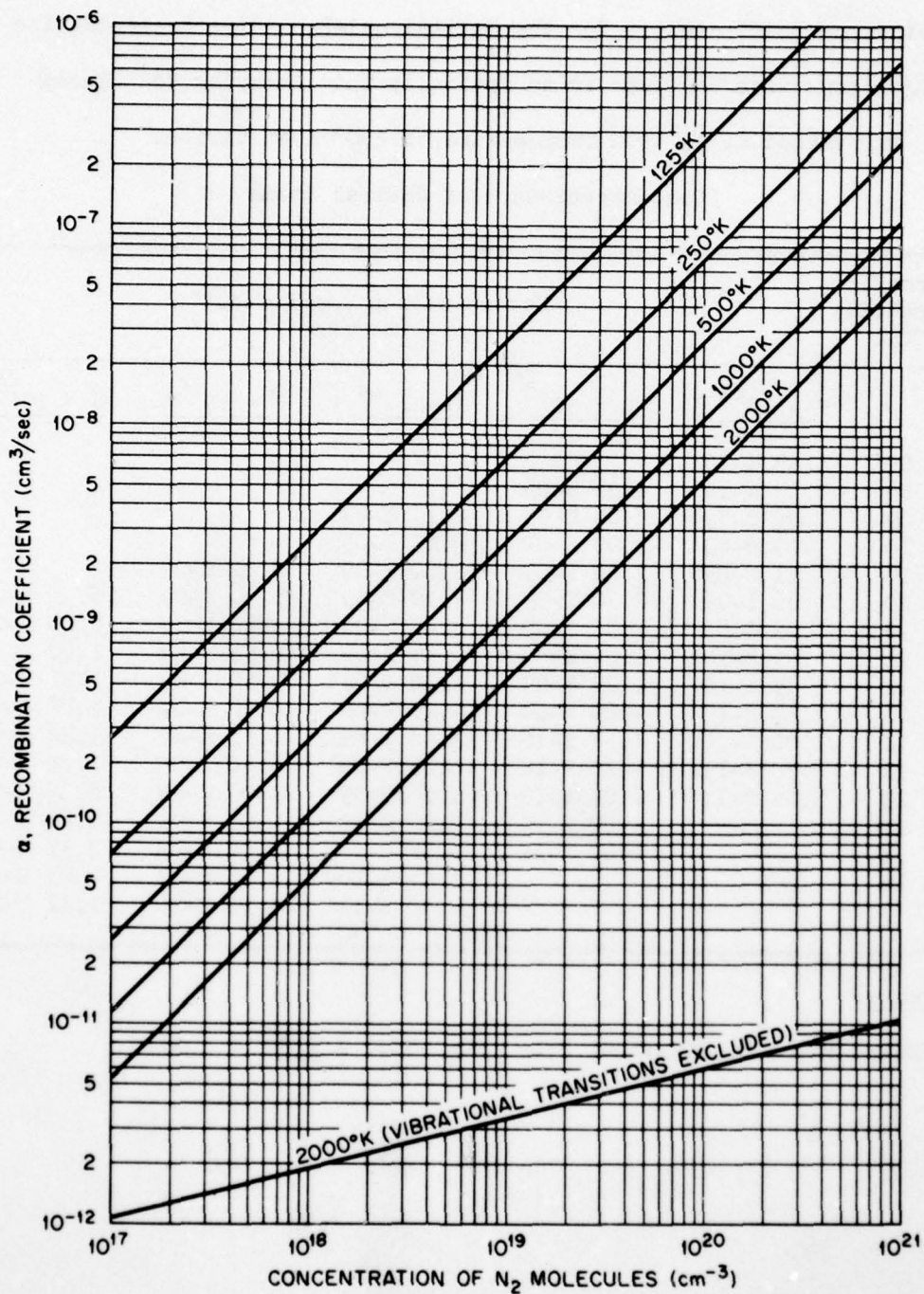
for Electrons with N_2^+ Ions in N_2^*

Concentration of N_2 Molecules (cm^{-3})	Recombination Coefficient α (cm^3/sec)					
	$T=125^\circ K$	$T=250^\circ K$	$T=500^\circ K$	$T=1000^\circ K$	$T=2000^\circ K$	$T=2000^\circ K^*$
1.0 E 17	2.72 E-10	6.95 E-11	2.61 E-11	1.15 E-11	5.46 E-12	1.07 E-12
3.0 E 17	7.90 E-10	2.05 E-10	7.80 E-11	3.35 E-11	1.60 E-11	1.40 E-12
1.0 E 18	2.65 E-09	6.90 E-10	2.60 E-10	1.10 E-10	5.30 E-11	1.90 E-12
3.0 E 18	8.00 E-09	2.05 E-09	7.70 E-10	3.25 E-10	1.60 E-10	2.50 E-12
1.0 E 19	2.65 E-08	6.90 E-09	2.60 E-09	1.09 E-09	5.30 E-10	3.35 E-12
3.0 E 19	7.90 E-08	2.00 E-08	7.80 E-09	3.25 E-09	1.60 E-09	4.40 E-12
1.0 E 20	2.65 E-07	6.85 E-08	2.60 E-08	1.07 E-08	5.40 E-09	5.90 E-12
3.0 E 20	7.95 E-07	2.00 E-07	7.80 E-08	3.20 E-08	1.60 E-08	7.80 E-12
1.0 E 21		6.78 E-07	2.61 E-07	1.04 E-07	5.41 E-08	1.02 E-11

Reference:

H.S.W. Massey and H.B. Gilbody, Electronic and Ionic Impact Phenomena, Vol. IV, Clarendon Press, Oxford (1974), p. 2153-2154.

* Vibrational transitions excluded.



Collisional-Radiative Recombination Coefficient α
for Electrons with N_2^+ Ions in N_2^*

Graphical Data C-5.19.

Tabular Data C-5.20.

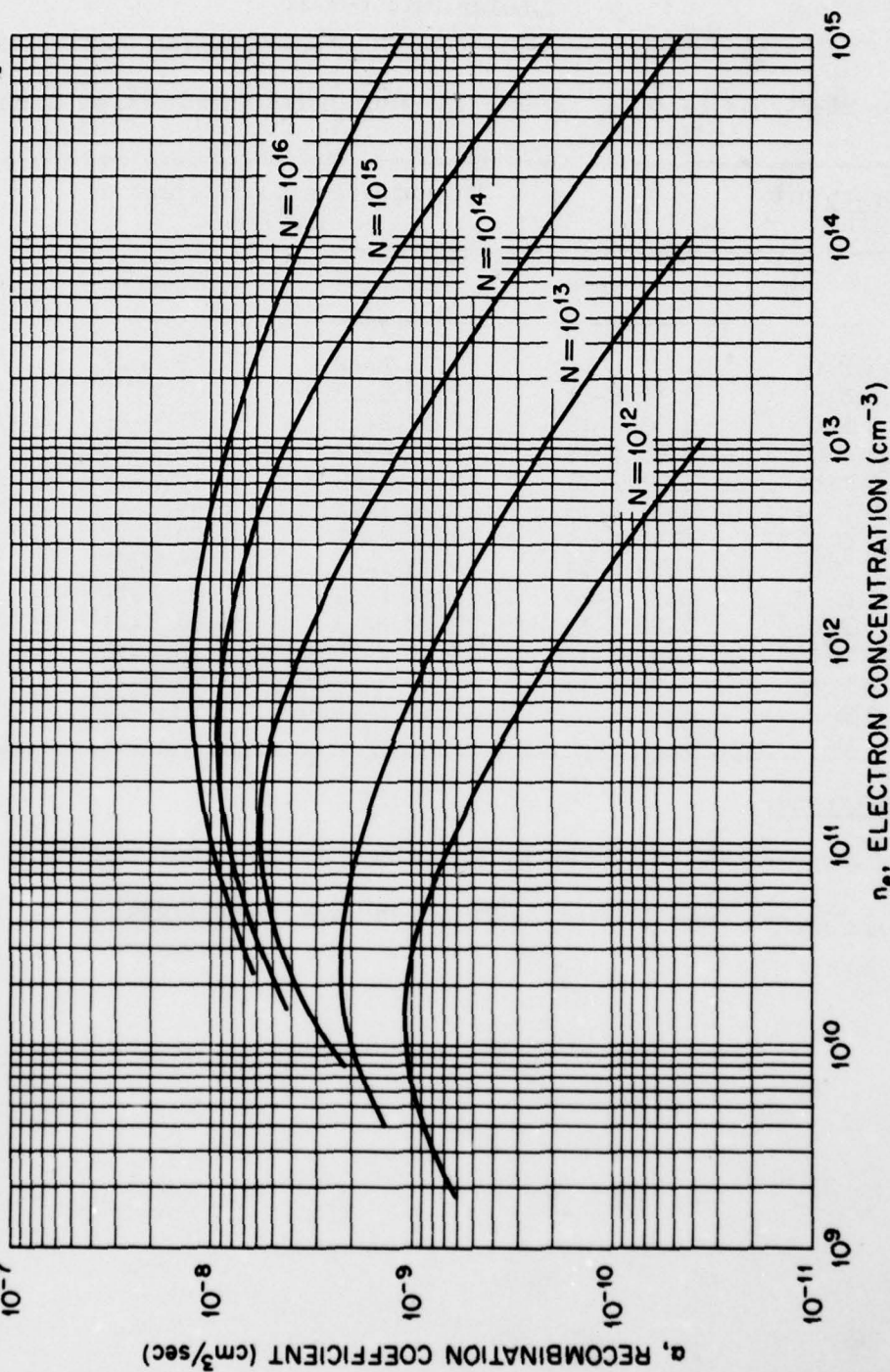
Recombination Coefficient α for the Collisional-Radiative Recombination
of Electrons with He^+ Ions in an Optically Thin Decaying He^+ Plasma
Maintained at an Atom Temperature of 250°K At Various
Concentrations N of Neutral Atoms

Electron Concentration $n_e (\text{cm}^{-3})$	Recombination Coefficient α (cm^3/sec)				
	$N = 10^{12}$	$N = 10^{13}$	$N = 10^{14}$	$N = 10^{15}$	$N = 10^{16}$
1.8 E 09	6.19 E-10				
4.0 E 09	8.80 E-10	1.39 E-09			
7.9 E 09	1.05 E-09	1.85 E-09	2.17 E-09		
1.0 E 10	1.09 E-09	2.00 E-09	2.60 E-09		
1.5 E 10	1.11 E-09	2.20 E-09	3.80 E-09	4.20 E-09	
2.2 E 10	1.06 E-09	2.30 E-09	4.10 E-09	5.10 E-09	6.11 E-09
2.6 E 10	1.03 E-09	2.33 E-09	4.40 E-09	5.40 E-09	6.60 E-09
1.0 E 11	6.49 E-10	1.84 E-09	5.78 E-09	8.51 E-09	1.00 E-08
3.5 E 11	3.35 E-10	1.20 E-09	4.90 E-09	9.55 E-09	1.21 E-08
5.8 E 11	2.50 E-10	9.60 E-10	4.25 E-09	8.90 E-09	1.27 E-08
1.0 E 12	1.80 E-10	7.48 E-10	3.45 E-09	8.51 E-09	1.22 E-08
3.0 E 12	8.70 E-11	4.20 E-10	2.05 E-09	6.40 E-09	1.10 E-08
1.0 E 13	3.44 E-11	2.07 E-10	1.06 E-09	4.20 E-09	8.32 E-09
3.0 E 13		1.00 E-10	5.20 E-10	2.25 E-09	5.60 E-09
1.0 E 14		4.00 E-11	2.28 E-10	1.04 E-09	3.45 E-09
3.0 E 14			1.05 E-10	4.90 E-10	2.05 E-09
1.0 E 15			4.46 E-11	1.98 E-10	1.11 E-09

Reference:

D.R. Bates and A.E. Kingston, Proc. Roy. Soc. A 279, 32 (1964).

Recombination coefficient α for the collisional-radiative recombination of electrons with He^+ ions in an optically thin decaying He^+ plasma maintained at an atom temperature of 250°K at various concentrations N of neutral atoms



Graphical Data C-5.21

Tabular Data C-5.22.

Calculated Collisional-Dielectronic Recombination Coefficient α
for Electrons in an He^+ Plasma for Four Different Electron Concentrations n_e

Temperature (°K)	Recombination Coefficient α (cm^3/sec)			
	$n_e = 10^{16}$	$n_e = 10^{12}$	$n_e = 10^8$	$n_e = 10^4$
2.4 E 03		1.00 E-12	6.49 E-13	5.53 E-13
2.6 E 03	1.76 E-11	8.80 E-13	6.00 E-13	5.20 E-13
3.0 E 03	7.45 E-12	6.87 E-13	5.31 E-13	4.66 E-13
1.0 E 04	4.55 E-13	2.18 E-13	2.18 E-13	2.18 E-13
2.0 E 04	1.88 E-13	2.51 E-13	3.76 E-13	5.08 E-13
3.0 E 04	1.37 E-13	3.26 E-13	6.49 E-13	1.05 E-12
5.0 E 04	8.95 E-14	4.26 E-13	1.00 E-12	1.64 E-12
1.0 E 05	5.93 E-14	4.75 E-13	1.25 E-12	2.17 E-12
3.0 E 05	2.31 E-14	3.26 E-13	8.32 E-13	1.49 E-12
5.0 E 05	1.28 E-14	2.18 E-13	5.31 E-13	9.18 E-13
1.0 E 06	5.92 E-15	9.16 E-14	2.30 E-13	3.77 E-13
1.2 E 06	3.83 E-15	7.00 E-14	1.75 E-13	3.00 E-13
2.5 E 06		2.07 E-14	5.93 E-14	9.16 E-14

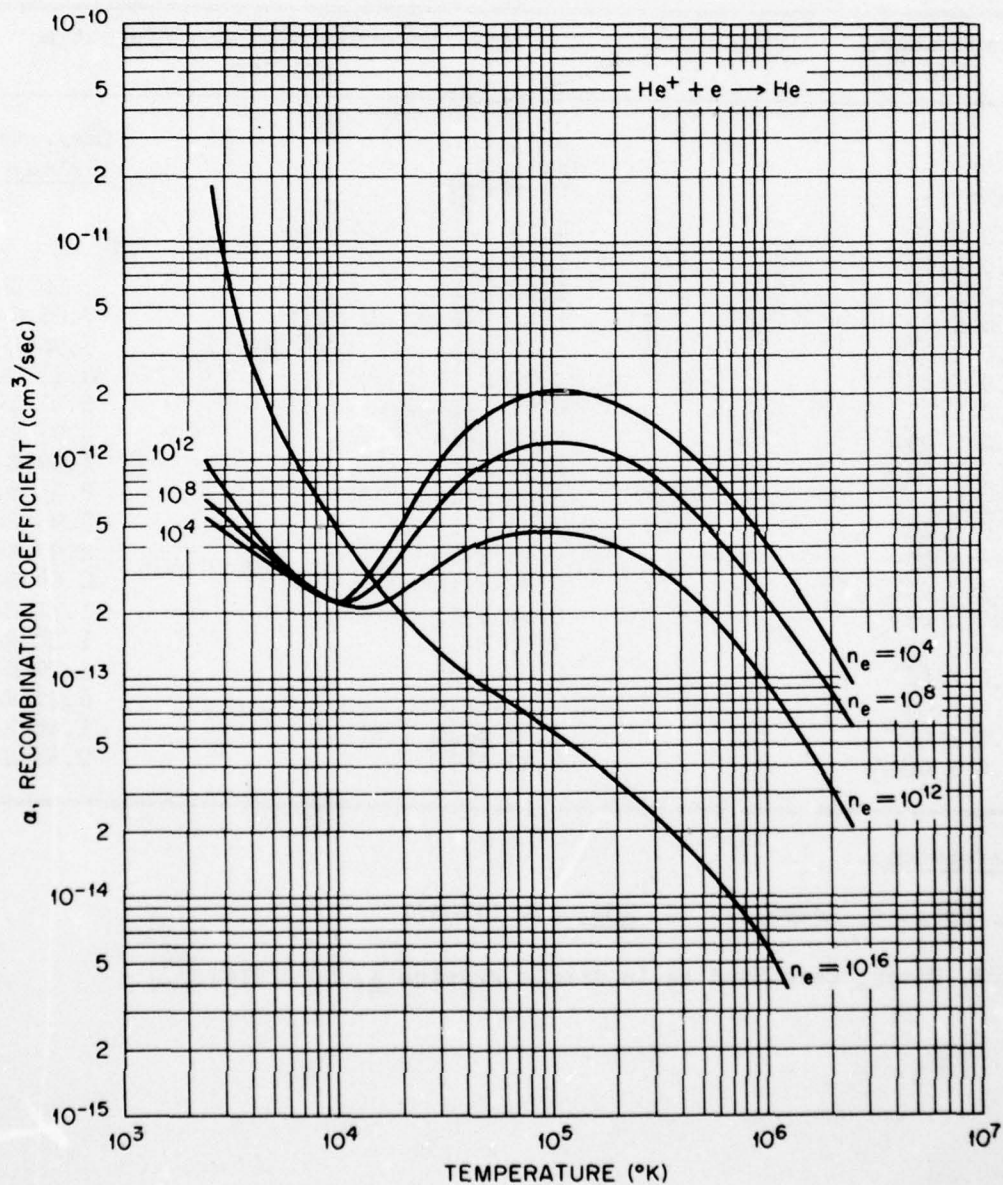
Reference:

A. Burgess and H.P. Summers, *Astrophys. J.* 157, 1007 (1969).

D.R. Bates, *Case Studies in Atomic Physics* 4, 57 (1974).

Graphical Data C-5.23.

Calculated Collisional-Dielectronic Recombination Coefficient α
for Electrons in an He^+ Plasma for Four Different Electron Concentrations n_e



Tabular Data C-5.24.

Total Recombination Coefficients α for the Radiative
and Dielectronic Recombination of He^+ Ions with Electrons

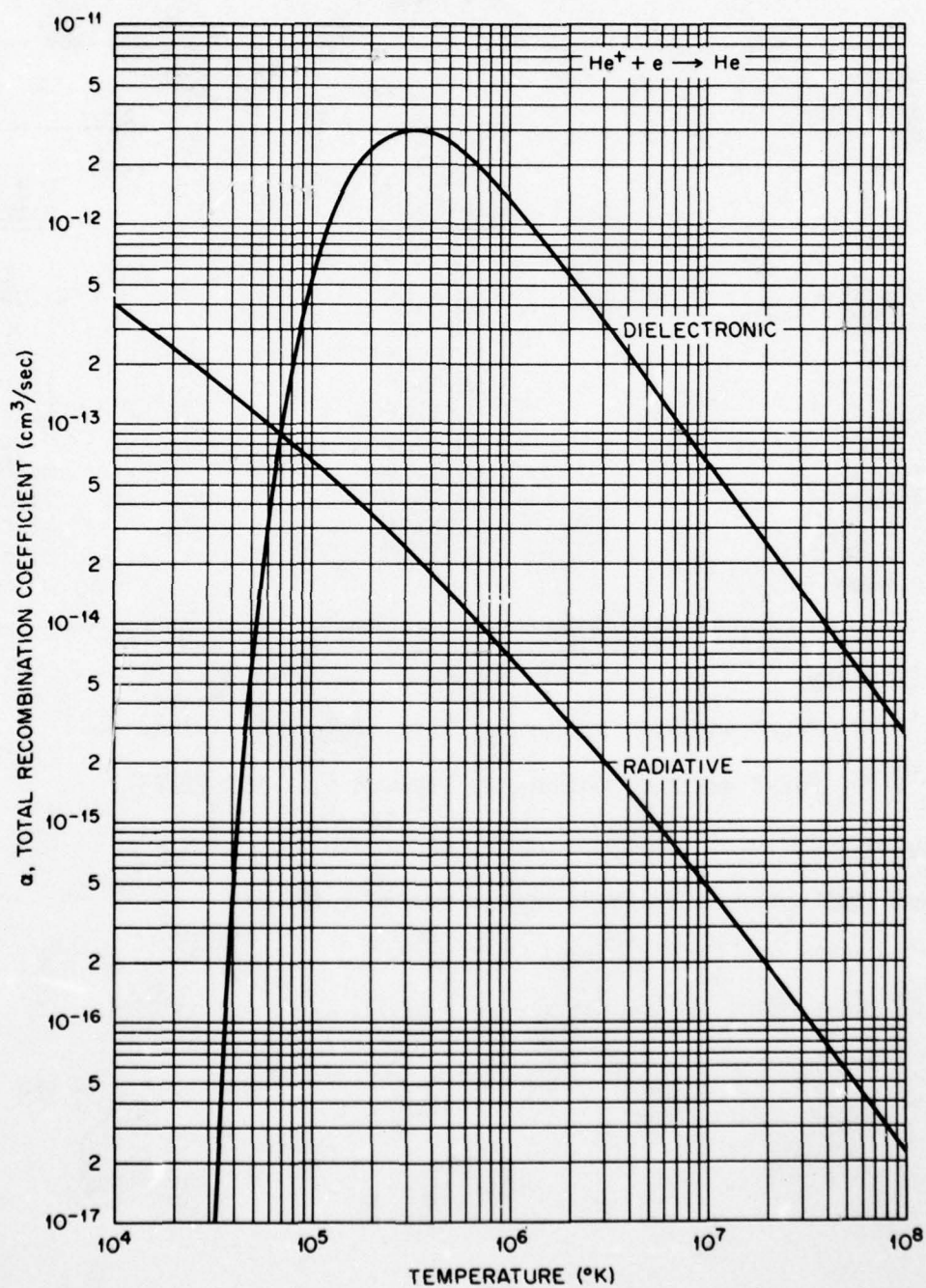
Temperature (°K)	Total Recombination Coefficient α (cm ³ /sec)	
	Radiative <u>$\text{He}^+ + e \rightarrow \text{He}$</u>	Dielectronic <u>$\text{He}^+ + e \rightarrow \text{He}$</u>
1.0 E 04	4.19 E-13	
3.0 E 04	1.88 E-13	
3.2 E 04	1.68 E-13	1.00 E-17
4.0 E 04	1.41 E-13	7.05 E-16
5.0 E 04	1.18 E-13	5.96 E-15
8.0 E 04	7.80 E-14	2.17 E-13
1.0 E 05	6.81 E-14	5.43 E-13
1.2 E 05	5.60 E-14	8.97 E-13
1.5 E 05	4.55 E-14	1.59 E-12
2.0 E 05	3.45 E-14	2.35 E-12
3.0 E 05	2.30 E-14	2.95 E-12
3.3 E 05	2.15 E-14	2.95 E-12
5.0 E 05	1.42 E-14	2.64 E-12
8.0 E 05	8.50 E-15	1.71 E-12
1.0 E 06	7.08 E-15	1.38 E-12
3.0 E 06	2.02 E-15	3.29 E-13
1.0 E 07	4.4 E-16	6.28 E-14
3.0 E 07	1.05 E-16	1.48 E-14
1.0 E 08	2.11 E-17	2.68 E-15

Reference:

A. Burgess, Astrophys. J. 139, 776 (1964).

D.R. Bates, Case Studies in Atomic Physics 4, 57 (1974).

Total Recombination Coefficients α for the Radiative
and Dielectronic Recombination of He^+ Ions with Electrons



Graphical Data C-5.25.

Tabular Data C-5.26.

Cross Sections for Dissociative Recombination of Electrons

with H_2^+ and D_2^+ Ions

Energy (eV)	Cross Sections (cm^2)	
	$e + H_2^+ \rightarrow$ <u>Neutrals</u>	$e + D_2^+ \rightarrow$ <u>Neutrals</u>
3.0 E-01	2.33 E-15	1.79 E-15
4.0 E-01	1.99 E-15	1.66 E-15
5.0 E-01	1.75 E-15	1.53 E-15
6.0 E-01	1.47 E-15	1.41 E-15
8.0 E-01	8.90 E-16	1.14 E-15
1.0 E 00	6.30 E-16	9.00 E-16
1.5 E 00	4.67 E-16	6.48 E-16
2.0 E 00	3.49 E-16	5.13 E-16
2.5 E 00	2.71 E-16	4.10 E-16
3.0 E 00	2.20 E-16	3.35 E-16
4.0 E 00		2.36 E-16

References:

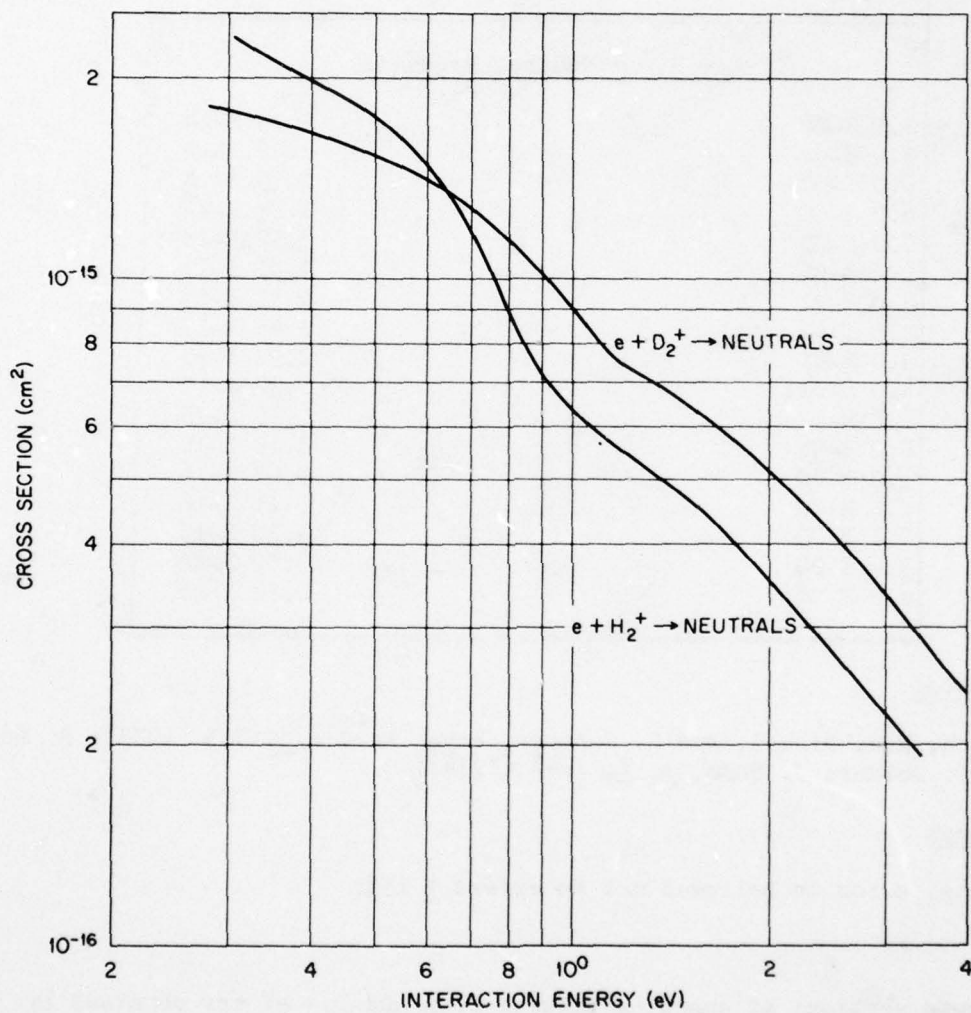
H_2^+ : B. Peart and K.T. Dolder, J. Phys. B 7, 236 (1974).

D_2^+ : B. Peart and K.T. Dolder, J. Phys. B 6, L-359 (1973).

Accuracy:

The total error is believed not to exceed $\pm 10\%$.

Cross Sections for Dissociative Recombination of Electrons
with H_2^+ and D_2^+ Ions



Graphical Data C-5.27.

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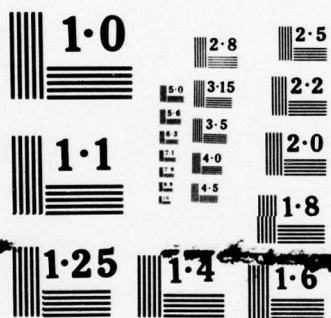
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MICROCOPY RESOLUTION TEST CHART

Tabular Data C-5.28.

Cross Section for Dissociative Recombination of Electrons with H_3^+ Ions

Energy (eV)	Cross Section (cm ²)
<u>$e + H_3^+ \rightarrow$ Neutral Products</u>	
2.5 E-02	2.73 E-14
3.0 E-02	2.32 E-14
4.0 E-02	1.79 E-14
6.0 E-02	1.23 E-14
8.0 E-02	9.52 E-15
1.0 E-01	7.80 E-15
2.0 E-01	4.17 E-15
2.5 E-01	3.40 E-15
3.0 E-01	2.90 E-15
4.0 E-01	2.22 E-15
6.0 E-01	1.53 E-15
8.0 E-01	1.19 E-15
1.0 E 00	9.65 E-16
2.0 E 00	5.18 E-16
2.5 E 00	4.20 E-16
3.0 E 00	3.58 E-16
4.0 E 00	2.76 E-16

References:

M.T. Leu, M.A. Biondi, and R. Johnsen, Phys. Rev. A 8, 413 (1973); B. Peart and K.T. Dolder, J. Phys. B. 7, 1948 (1974).

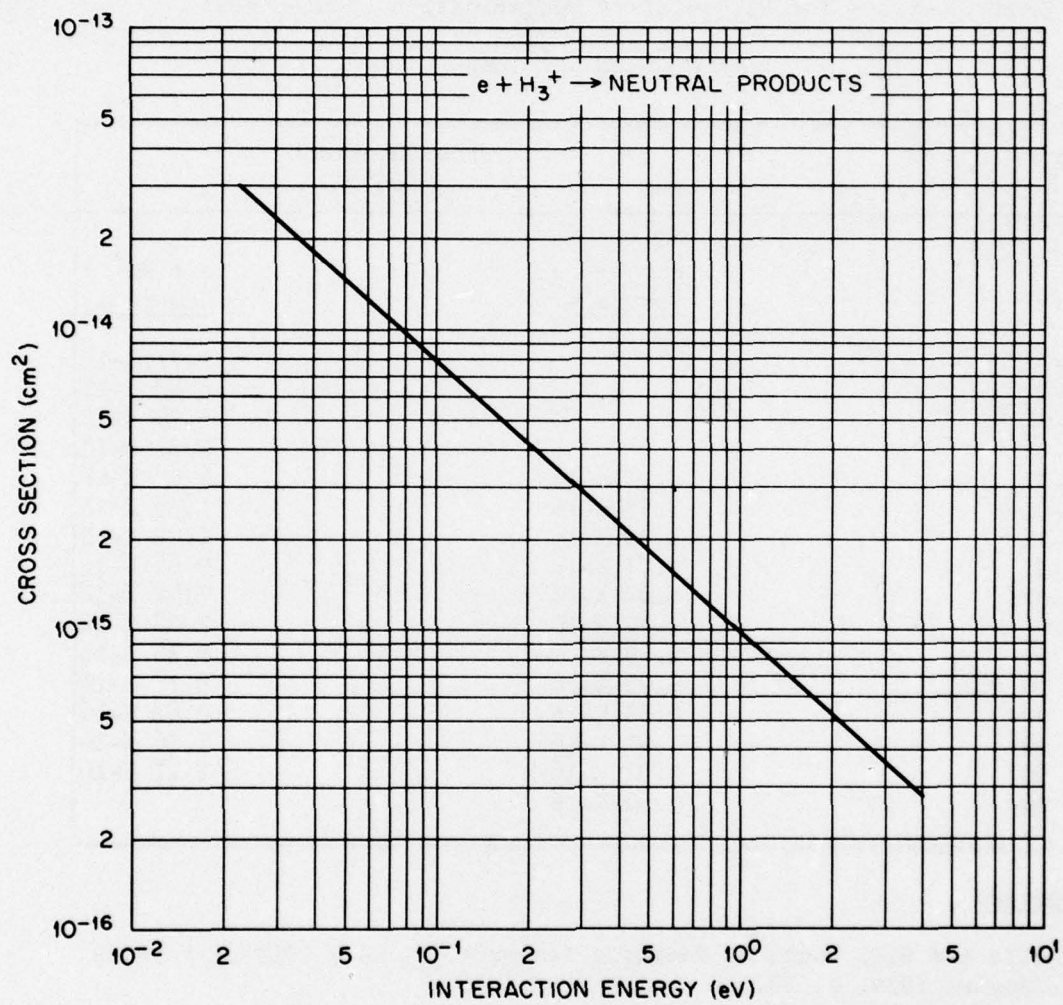
Accuracy:

The total error is believed not to exceed + 15%.

Note:

The cross sections at energies between 0.05 and 0.4 eV are obtained by interpolating between the low energy microwave afterglow data of Leu, et al., and the higher-energy inclined beam data of Peart and Dolder.

Cross section for dissociative recombination of electrons with H_3^+ ions



Graphical Data C-5.29.

Tabular Data C-5.30.

Cross Sections for Dissociative Recombination of Electrons

with O_2^+ and NO^+ Ions

Energy (eV)	Cross Sections (cm^2)	
	$e + O_2^+ \rightarrow$ <u>Neutrals</u>	$e + NO^+ \rightarrow$ <u>Neutrals</u>
4.0 E-02		1.57 E-14
6.0 E-02		8.40 E-15
8.0 E-02		5.39 E-15
1.0 E-01		3.81 E-15
1.5 E-01	2.13 E-15	2.05 E-15
2.0 E-01	1.55 E-15	1.35 E-15
3.0 E-01	1.00 E-15	1.22 E-15
4.0 E-01	7.27 E-16	9.66 E-16
6.0 E-01	4.68 E-16	7.42 E-16
8.0 E-01	3.40 E-16	7.08 E-16
1.0 E 00	2.69 E-16	5.38 E-16
1.5 E 00	6.90 E-16	2.77 E-16
2.0 E 00	2.85 E-16	2.82 E-16
3.0 E 00	1.91 E-16	1.76 E-16
4.0 E 00	1.87 E-16	1.77 E-16
6.0 E 00	2.00 E-16	

References:

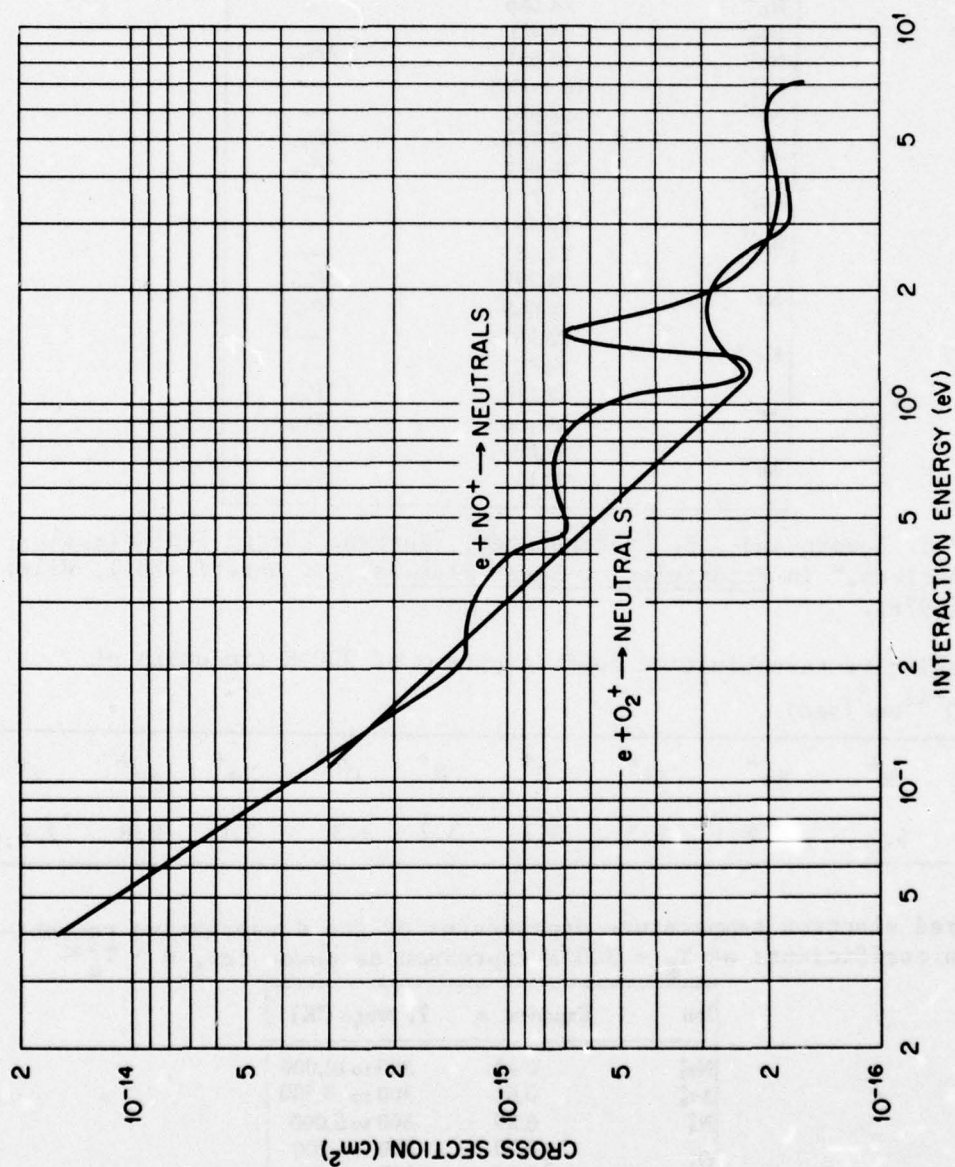
F.L. Walls and G.H. Dunn, J. Geophys. Research 79, 1911 (1974); Physics Today, August 1974, p. 30.

Accuracy:

The total error is believed not to exceed $\pm 30\%$.

Cross Sections for Dissociative Recombination of Electrons

with O_2^+ and NO^+ Ions



Graphical Data C-5.31.

Tabular Data C-5.32.

Recombination energies of rare gas ions

(a)

Ion	Recombination energy (eV)	Spectroscopic designation
He ⁺	24.586	² S
He ₂ ⁺	19-21	—
Ne ⁺	21.661	² P _{1/2}
Ne ₂ ⁺	18.9-19.3	—
Ne ⁺²	41.076	—
Ar ⁺	15.759	² P _{3/2}
Ar ₂ ⁺	15.937	² P _{1/2}
Ar ⁺²	?	—
	27.45	—
	27.63	—
Kr ⁺	13.999	² P _{3/2}
	14.665	² P _{1/2}
Kr ⁺²	23.905	—
	24.57	—
Xe ⁺	12.130	² P _{3/2}
	13.436	² P _{1/2}
Xe ⁺²	19.89	—
	21.17	—

From M.T. Bowers and J.B. Laudenslager, "Thermal Energy Ion-Molecule Interactions," in Principles of Laser Plasmas, (G. Bekefi, Ed.), Wiley, N.Y. (1976).

(b) Radiative recombination coefficients α at 300°K (in units of $10^{-12} \text{ cm}^3/\text{sec}$)

Ion	H ⁺	He ⁺	Li ⁺	C ⁺	N ⁺	O ⁺	Ne ⁺	Na ⁺	K ⁺
α	4.2	4.2	3.3	3.7	3.2	3.3	3.0	2.8	2.6

Measured electron temperature dependences of the dissociative recombination coefficients at $T_g = 300^\circ\text{K}$ expressed as power law, $\alpha \sim T_e^{-x}$.

(c)

Ion	Exponent x	T_e range (°K)
Ne ₂ ⁺	0.43	300 to 12,000
Ar ₂ ⁺	0.61	300 to 8,500
N ₂ ⁺	0.39	300 to 5,000
O ₂ ⁺	{ 0.70	300 to 1,200
	{ 0.56	1,200 to 5,000
	{ 0.37	380 to 5,500
NO ⁺	{ 0.83	200 to 5,000
	{ ~0.5	10 ⁴ to 10 ⁵

From M. A. Biondi, "Recombination," in Principles of Laser Plasmas (G. Bekefi, Ed.), Wiley, N.Y. (1976). Newer data for Ar₂⁺ have been substituted--see Y. J. Shiu and M. A. Biondi, Phys. Rev. A. (1978).

Tabular Data C-5.33.

Dependence of the dissociative recombination coefficient α (300°K) on molecular ion complexity. The number of atoms in the ion and the mean atomic number per atom in the ion are the parameters. (α in units of cm^3/sec).

	Mean atomic no.	Number of atoms			
		2	3	4	5
(a)	1	H_2^+ ?	H_3^+ 2.3[-7]		$\text{H}_3^+\cdot\text{H}_2$ ~3[-6]
	2	He_2^+ 1[-8]			
	3			H_3O^+ ~1[-6]	
	5		HCO^+ 2.0[-7]		
	7	N_2^+ 2.2[-7]		$\text{N}_2^+\cdot\text{N}_2$ ~2[-6]	
	7½	NO^+ 4.1[-7]	CO_2^+ 3.8[-7]	$\text{NO}^+\cdot\text{NO}$ 1.7[-6]	
	8	O_2^+ 2.1[-7]		$\text{O}_2^+\cdot\text{O}_2$ ~2[-6]	
	10	Ne_2^+ 1.8[-7]			
	18	Ar_2^+ 9.1[-7]	- Y. J. Shiu and M. A. Biondi, Phys. Rev. A (1978)		
	36	Kr_2^+ 1.6[-6]	- Y. J. Shiu and M. A. Biondi, Phys. Rev. A <u>16</u> , 1817 (1977)		
	54	Xe_2^+ 2.3[-6]	- Y. J. Shiu, M. A. Biondi and D. P. Sipler, Phys. Rev. A <u>16</u> , 1817 (1977).		

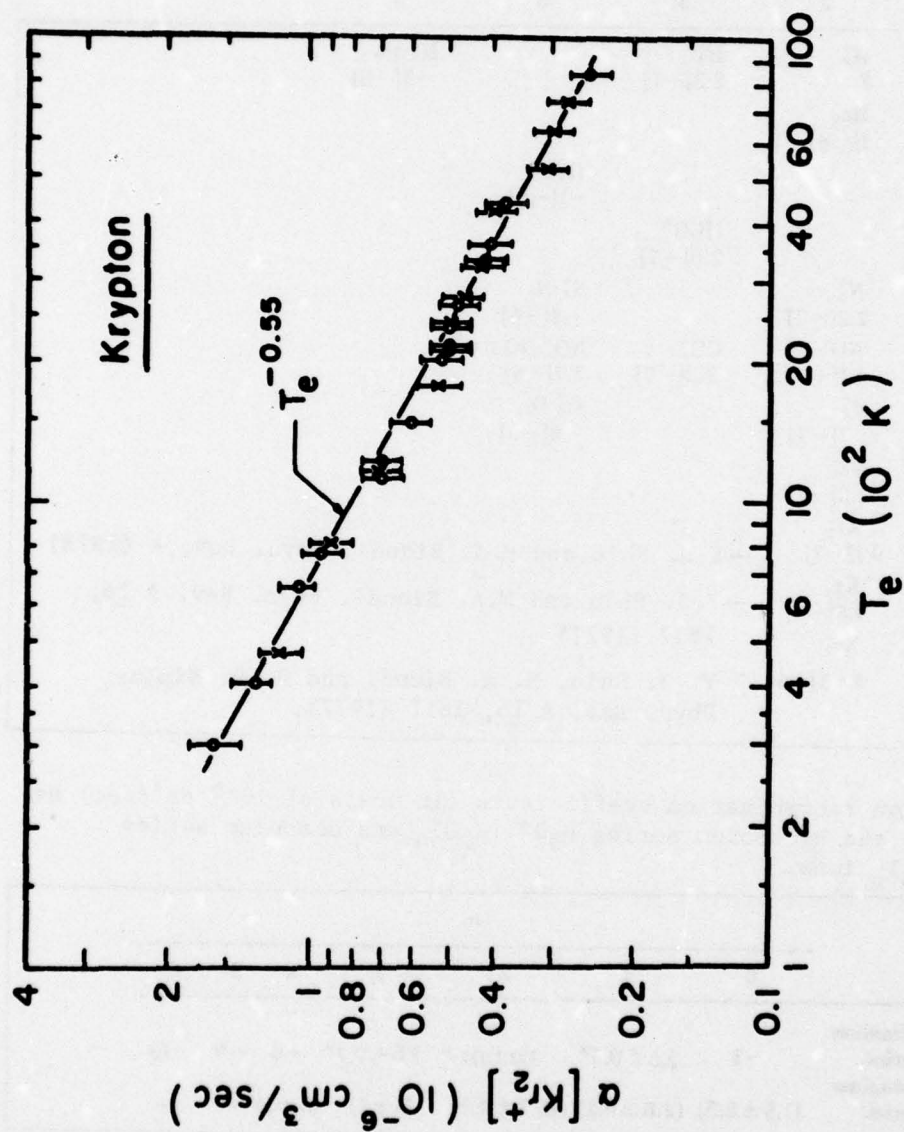
(b)

Cluster-ion recombination coefficients (in units of $10^{-6} \text{ cm}^3/\text{sec}$) at 300°K for the hydronium series $\text{H}_3\text{O}^+(\text{H}_2\text{O})_n$ and ammonium series $\text{NH}_4^+(\text{NH}_3)_n$ ions.

Ion	n						
	0	1	2	3	4	5	6
Hydronium series	~1	$2.5 \pm 0.5^*$	$3.0 \pm 0.6^*$	$3.6 \pm 0.7^*$	~6	~9	~10
Ammonium series	(1.5 ± 0.3)	(2.8 ± 0.2)	(2.7 ± 0.2)	(3 ± 1)	(3 ± 1)	—	—

* C. M. Huang, M. Whittaker, M. A. Biondi, and R. Johnsen; Phys. Rev. A (1978).

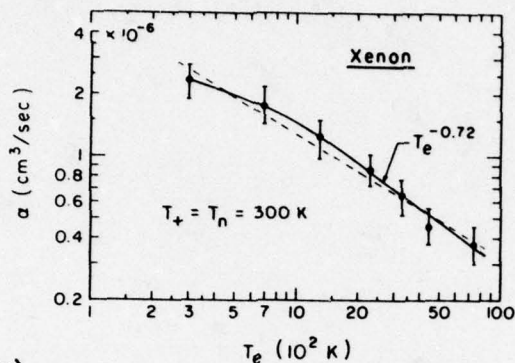
From M.A. Biondi, "Recombination," in "Principles of Laser Plasmas" (G. Bekefi, Ed.), Wiley, N.Y. (1976). Newer data from Biondi's laboratory have been substituted where shown. The new references contain important information on the dependence of α on electron temperature and on the excited state population resulting from dissociative recombination.



Graphical Data C-5.34.

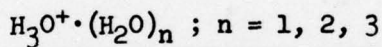
Measured variation of the rate coefficient for dissociative recombination of Kr_2^+ with electron temperature, for $T_+ = T_n = 300$ K. The solid line represents a simple, power-law variation as $T_e^{-0.55}$. Y. Shiu and M.A. Biondi, Phys. Rev. A, Nov., 1977.

Tabular and Graphical Data C-5.35.



(a) Variation of $\alpha(\text{Xe}_2^+)$ with electron temperature at $T_+ = T_n = 300 \text{ K}$.

Y.J. Shiu, M.A. Biondi, and D.P. Sipler, Phys. Rev. A. 15, 494 (1977).



$$\begin{aligned}\alpha(37^+) &= (2.5 \pm 0.5) \times 10^{-6} \left[300/T_e(\text{K}) \right]^{0.08} \\ \alpha(55^+) &= (3.0 \pm 0.6) \times 10^{-6} \left[300/T_e(\text{K}) \right]^{0.08} \\ \alpha(73^+) &= (3.6 \pm 0.7) \times 10^{-6} \left[300/T_e(\text{K}) \right]^{0.00}\end{aligned}$$

The values are in cm^3/sec and have been determined over the range,
 $(300 - 400 \text{ K}) \leq T_e \leq (6000 - 8000 \text{ K})$.

(b) Electron temperature dependence of α for the hydronium series ions $\text{H}_3\text{O}^+ \cdot (\text{H}_2\text{O})_n$.

C.M. Huang, M. Whittaker, M.A. Biondi, and R. Johnsen, Phys. Rev. A (1978).

C-6. NEGATIVE ION FORMATION BY ELECTRON IMPACT

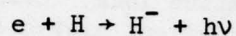
- D C.F. Barnett, J.A. Ray, E. Ricci, I. Wilker, E.W. McDaniel, E.W. Thomas and H.B. Gilbody, "Atomic Data for Controlled Fusion Research," Controlled Fusion Atomic Data Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee (Feb., 1977). Reports ORNL 5206, 680 pages.
- D,R H.S.W. Massey, "Negative Ions," Cambridge University Press, New York (1976). Excellent presentation and discussion of data up to April 1974.

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Tabular Data C-6.1.

Cross Section for Radiative Attachment of Electrons
to Ground-State Hydrogen Atoms (Theoretical)



Electron Energy (eV)	Cross Section (cm ²)
1.35 E-01	4.56 E-24
2.00 E-01	5.02 E-24
3.00 E-01	5.45 E-24
4.00 E-01	5.70 E-24
5.00 E-01	5.82 E-24
6.00 E-01	5.86 E-24
7.00 E-01	5.86 E-24
8.00 E-01	5.83 E-24
1.00 E 00	5.70 E-24
1.50 E 00	5.20 E-24
2.00 E 00	4.62 E-24
3.00 E 00	3.91 E-24
4.00 E 00	3.50 E-24
6.00 E 00	3.08 E-24
8.00 E 00	2.87 E-24
1.00 E 01	2.77 E-24
1.08 E 01	2.73 E-24

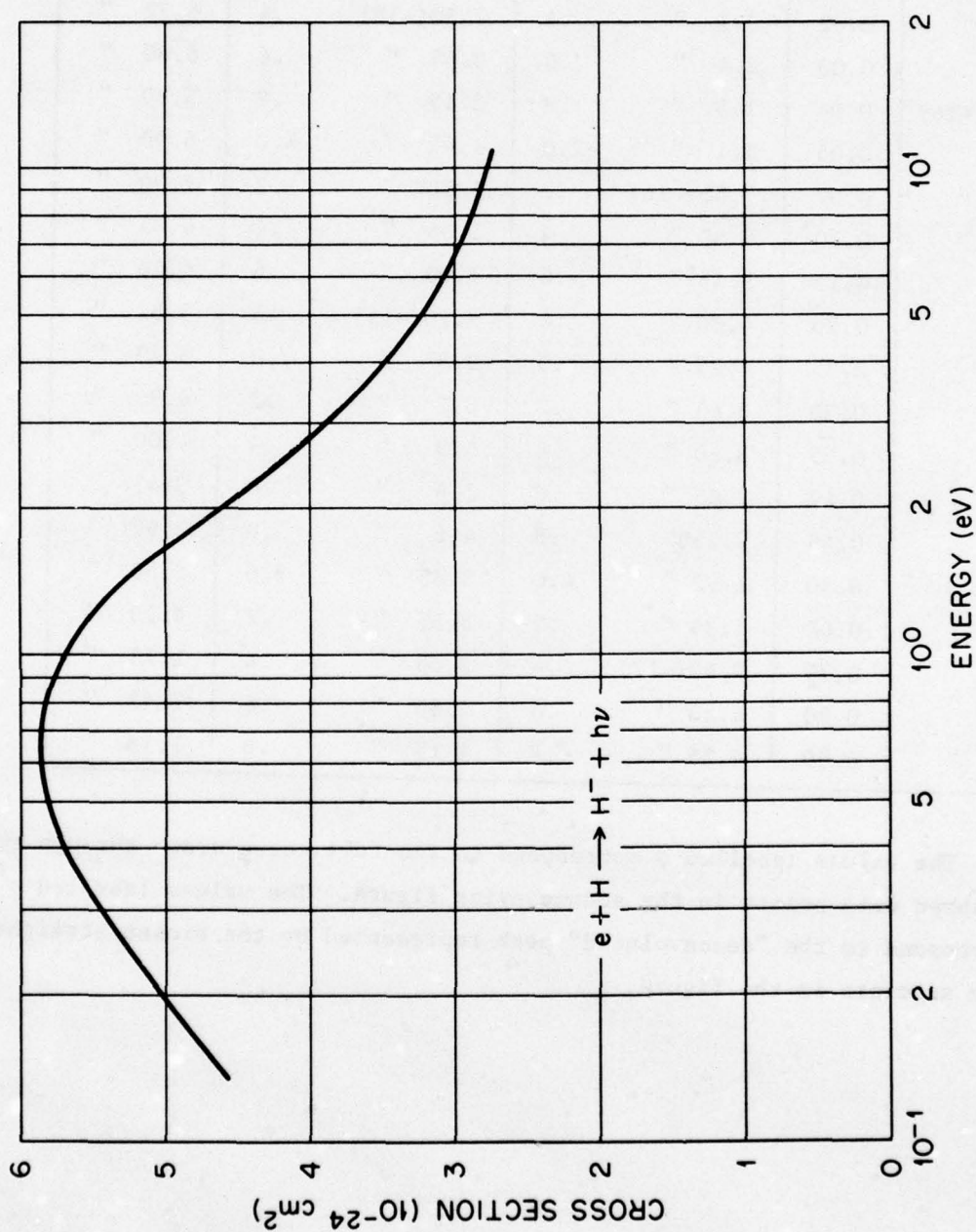
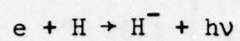
Reference:

H.S.W. Massey, E.H.S. Burhop, and H.B. Gilbody, "Electronic and Ionic Impact Phenomena," Vol. II, Oxford Univ. Press (1969), page 1260.

Accuracy:

The total error is believed not to exceed ± 5%.

Cross Section for Radiative Attachment of Electrons
to Ground-State Hydrogen Atoms (Theoretical)



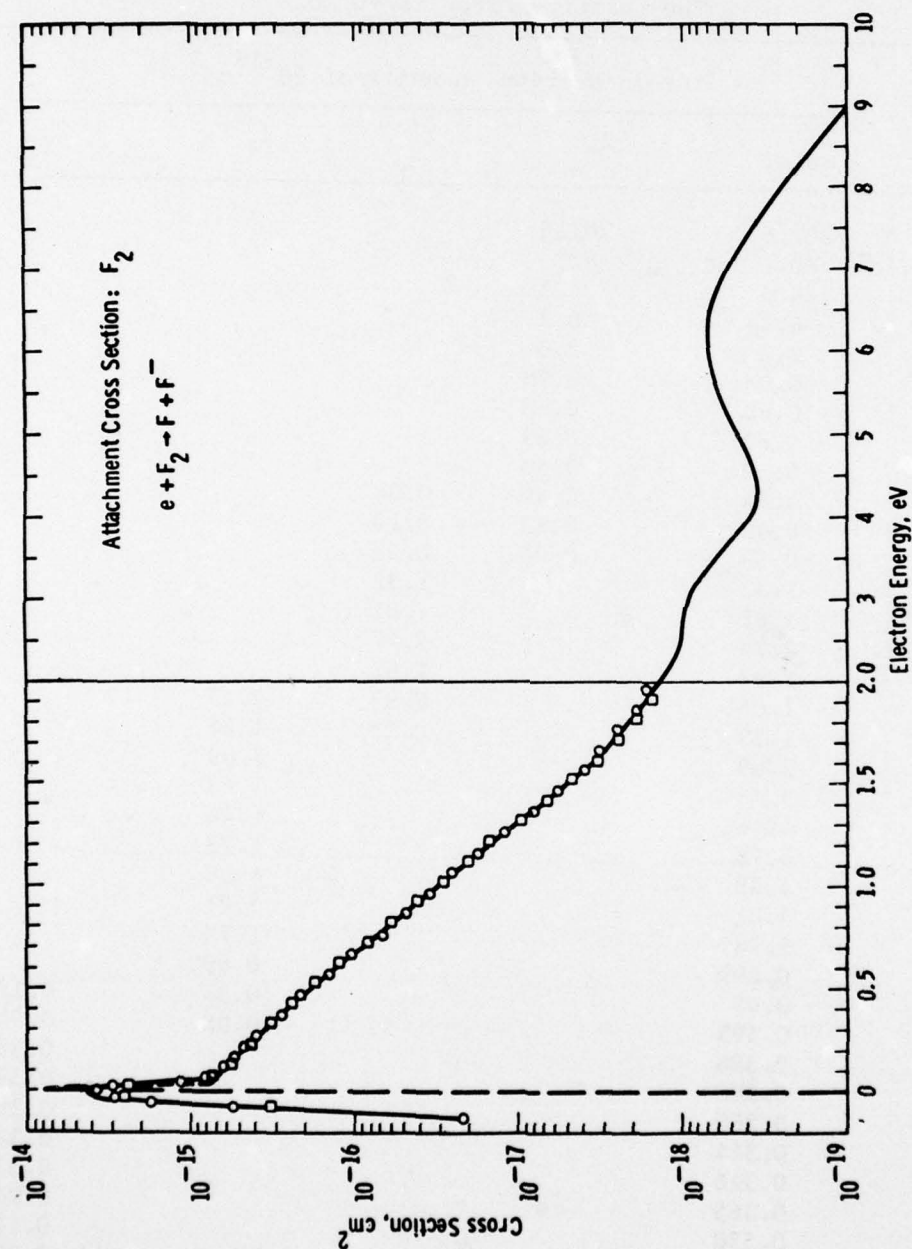
Graphical Data C-6.2.

Tabular Data C-6.3. Cross Section for Dissociative Attachment to F_2 Molecules.

σ' (cm^2)	ϵ (eV)	σ (cm^2)	ϵ (eV)	σ (cm^2)	ϵ (eV)	σ (cm^2)
8.0(-15)	0.00	4.0(-15)	1.0	3.20(-17)	5.0	4.65(-19)
4.44 "	0.01	3.8 "	.2	1.53 "	.2	5.18 "
2.47 "	0.02	3.1 "	.4	7.50(-18)	.4	5.72 "
1.37	0.03	2.4 "	.6	3.65 "	.6	6.30 "
8.20(-16)	0.04	1.5 "	.8	2.15 "	.8	6.80 "
7.40 "	0.05	1.1 "	2.0	1.42 "	6.0	6.90 "
7.10 "	0.07	7.50(-16)	.2	1.18 "	.2	7.00 "
6.50 "	0.10	6.50 "	.4	1.05 "	.4	6.85 "
	0.15	5.45 "	.6	1.00 "	.6	6.40 "
	0.20	4.80 "	.8	9.70(-19)	.8	5.82 "
	0.25	4.25 "	3.0	9.3 "	7.0	5.23 "
	0.30	3.65 "	.2	8.2 "	.2	4.90 "
	0.35	3.10 "	.4	6.9 "	.4	4.00 "
	0.40	2.65 "	.6	5.6 "	.6	3.45 "
	0.45	2.25 "	.8	4.6 "	.8	2.95 "
	0.50	1.92 "	4.0	3.85 "	8.0	2.50 "
	0.60	1.34 "	.2	3.55 "	.2	2.10 "
	0.70	9.40(-17)	.4	3.60 "	.4	1.73 "
	0.80	6.55 "	.6	3.80 "	.6	1.42 "
	0.90	4.55 "	.8	4.15 "	.8	1.18 "

The values labelled σ correspond to the full curve drawn through the measured data points in the accompanying figure. The values labelled σ' correspond to the "deconvoluted" peak represented by the broken straight line segments in the figure.

(P. J. Chantry - unpublished data, Feb. 10, 1978)



Graphical Data C-6.4. Cross Section for Dissociative Attachment to F_2 Molecules.

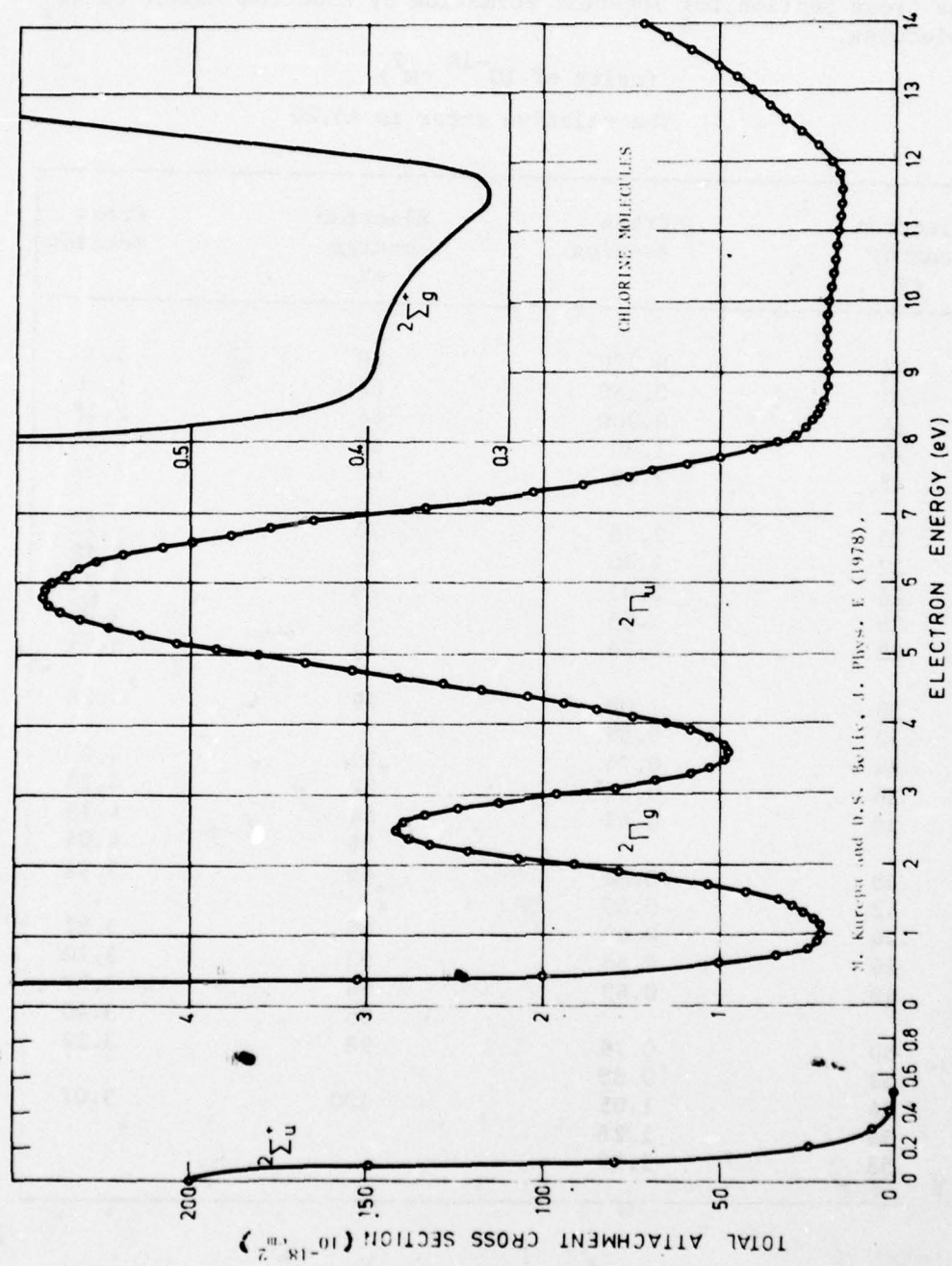
(P. J. Chantry - unpublished data, Feb. 10, 1978)

Tabular Data C-6.5.

Total and partial dissociative attachment
cross sections of the chlorine molecule
The relative error is ± 0.20

Electron energy [eV]	Cross section in units of 10^{-18} cm^2				
	total	$2\Sigma_u$	$2\Pi_g$	$2\Pi_u$	$2\Sigma_g^+$
0.0	201.6	201.6			
0.1	80.	80.			
0.2	24.5	24.5			
0.3	6.2	6.2			
0.4	2.0	2.0			
0.5	0.98	0.98			
0.6	0.68	0.68			
0.7	0.63	0.63			
0.8	0.50	0.50			
0.9	0.44	0.40	0.04		
1.0	0.42	0.32	0.10		
1.4	0.59	0.04	0.53		
1.8	1.32		1.32		
2.0	1.81		1.81		
2.4	2.77		2.77		
3.0	1.92		1.92		
3.4	1.06		0.93	0.13	
4.0	1.29		0.13	1.16	
4.4	2.09			2.09	
5.0	3.63			3.63	
5.4	4.46			4.46	
6.0	4.78			4.78	
6.4	4.38			4.38	
7.0	3.01			3.01	
7.4	1.78			1.78	
8.0	0.699			0.699	
8.4	0.45			0.33	0.12
9.0	0.395			0.05	0.345
9.4	0.386				0.386
10.0	0.380				0.380
10.4	0.365				0.365
11.0	0.344				0.344
11.4	0.316				0.316
12.0	0.365				0.245
12.4	0.530				0.170
13.0	0.510				0.050

M. Kurepa and D.S. Belic, J. Phys. E (1978).



Graphical Data C-6.6.

Tabular Data C-6.7.

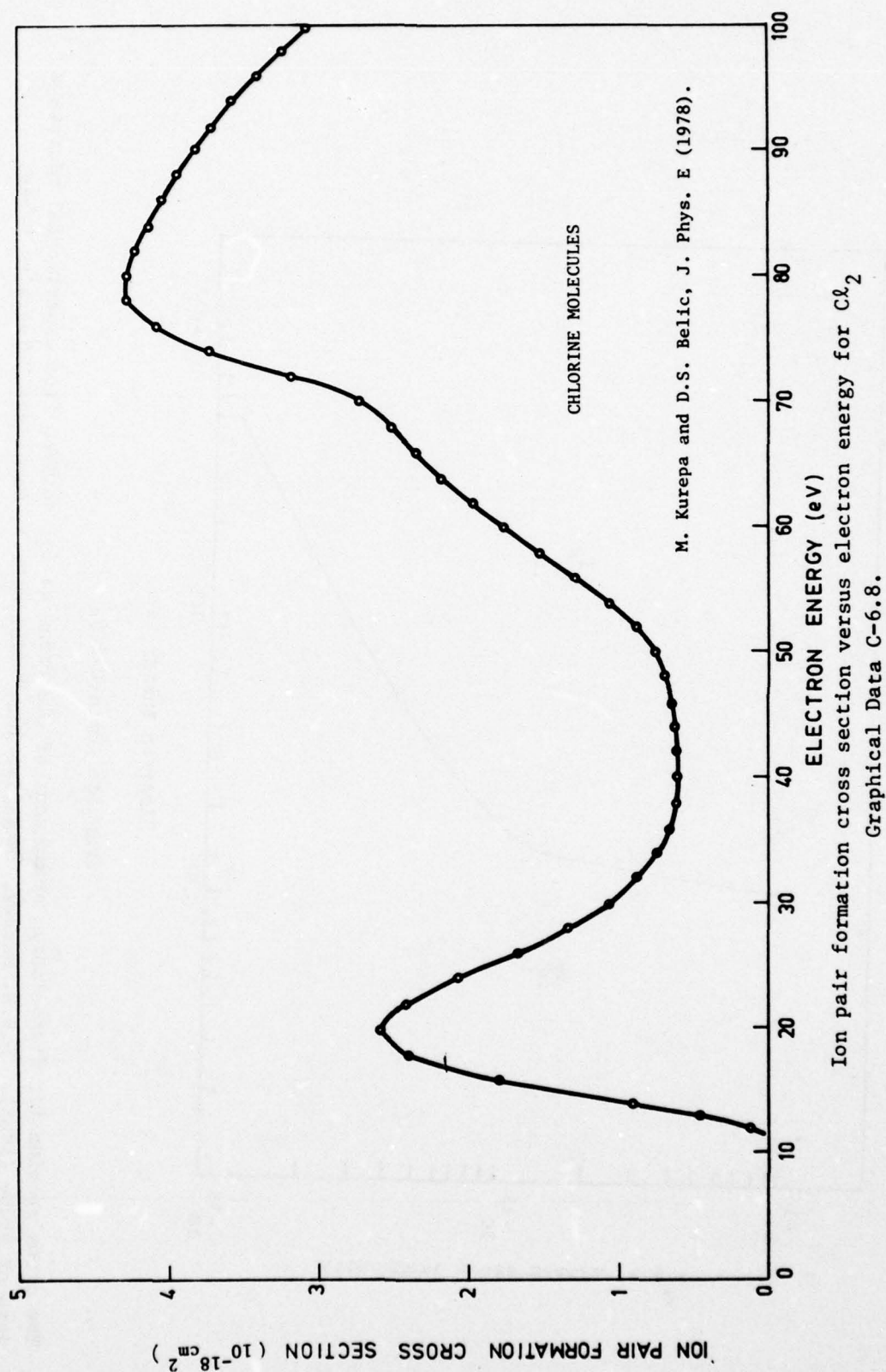
The Cross Section for Ion-Pair Formation by Electron Impact on Cl_2 Molecules.

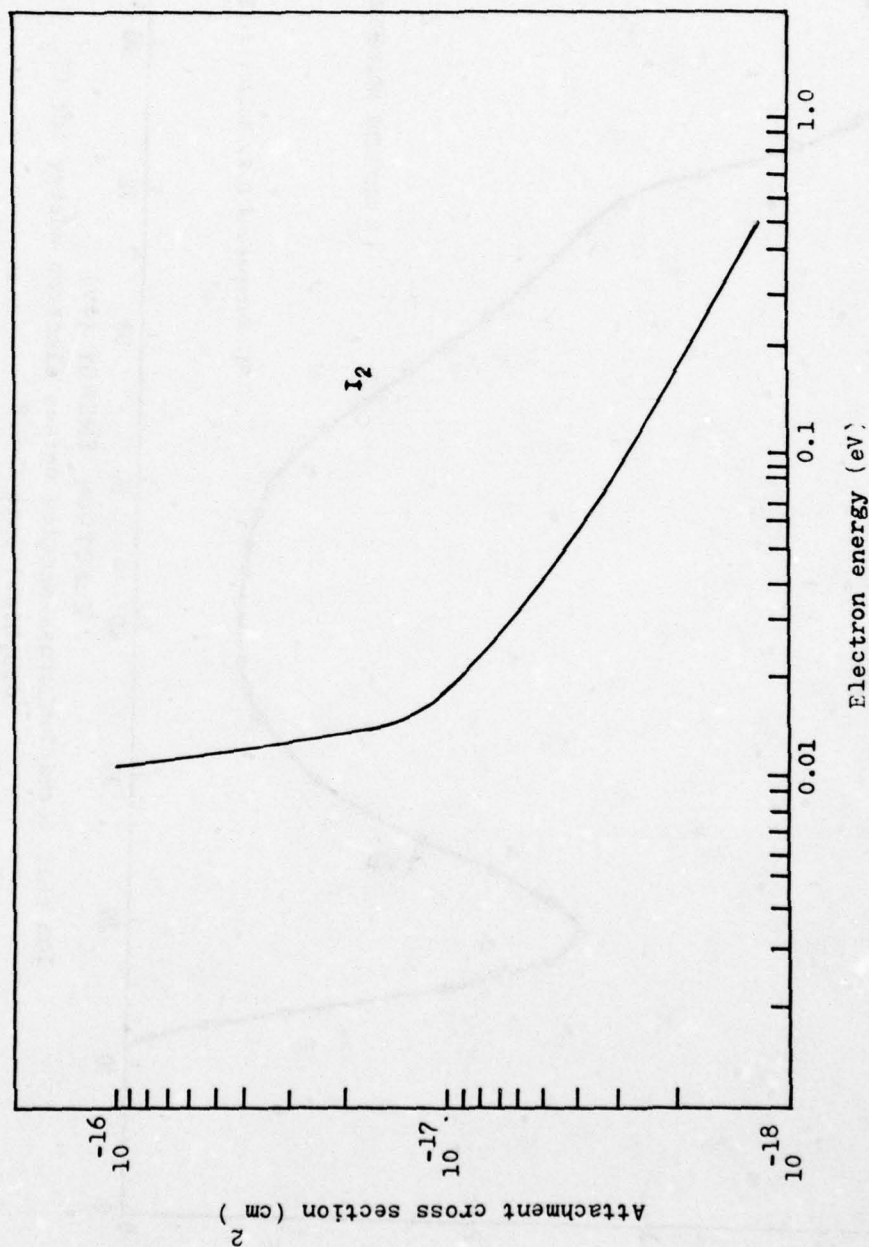
(units of 10^{-18} cm^2)

The relative error is ± 0.20

Electron energy eV	Cross section	Electron energy eV	Cross section
12	0.122	60	1.76
13	0.460	62	1.96
14	0.900	64	2.18
16	1.80	66	2.34
18	2.40	68	2.52
20	2.58	70	2.72
22	2.40	72	3.18
24	2.07	74	3.73
26	1.66	76	4.06
28	1.35	78	4.24
30	1.08	79	4.28
32	0.89	80	4.25
34	0.74	82	4.20
36	0.65	84	4.13
38	0.62	86	4.04
40	0.60	88	3.94
42	0.60	90	3.82
44	0.62	92	3.70
46	0.64	94	3.57
48	0.69	96	3.40
50	0.76	98	3.22
52	0.88	100	3.07
54	1.05		
56	1.28		
58	1.52		

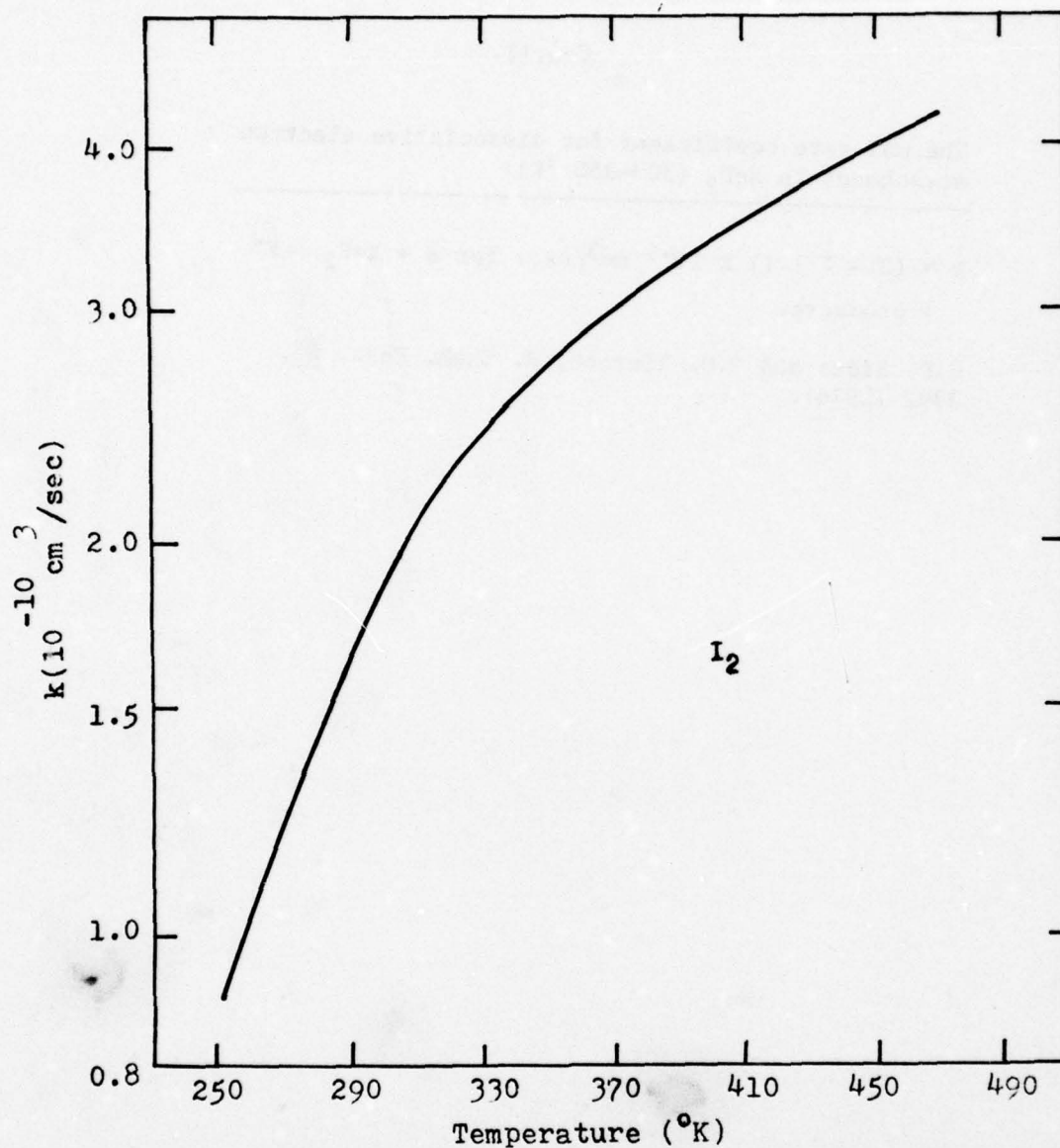
M. Kurepa and D. S. Belic, J. Phys. E (1978).





Graphical Data C-6.9.

The cross section for dissociative attachment of electrons to I₂, derived from experimental microwave data of Truby (1968). H.S.W. Massey, "Negative Ions" (Third Ed.), Cambridge University Press, Cambridge (1976), page 344.



Observed values for the electron attachment coefficient k for iodine vapor as a function of gas temperature. F. K. Truby, Phys. Rev 188, 508 (1969).

Electron attachment coefficient k in Br_2 at 296°K : $k = 0.82 \times 10^{-12} \text{ cm}^3/\text{sec}$.

F. K. Truby, Phys. Rev A. 4, 613 (1971).

This rate corresponds to an average cross section $\sigma \approx 0.8 \times 10^{-19} \text{ cm}^2$.

Graphical Data C-6.10.

C-6.11.

Thermal rate coefficient for dissociative electron attachment in XeF_2 (300-350 °K):

$$k = (2.4 \pm 1.1) \times 10^{-9} \text{ cm}^3/\text{sec. for } e + \text{XeF}_2 \rightarrow \text{F}^- + \text{products.}$$

G.D. Sides and T.O. Tiernan, J. Chem. Phys. 65, 3392 (1976).

D. PHOTON COLLISION PROCESSES IN GASES
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D. PHOTON COLLISION PROCESSES IN GASES

General References

- D,R J. A. R. Samson, "Photoionization of Atoms and Molecules", Physics Reports 28C, 303 (1976).
- D,R P. Lambropoulos, "Topics on Multiphoton Processes in Atoms", in D. R. Bates and B. Bederson, (Eds.), "Advances in Atomic and Molecular Physics", Vol. 12, pg. 87, Academic, New York (1976).
- D,R G. V. Marr and J. B. West, "Absolute Photoionization Cross Section Tables for Helium, Neon, Argon and Krypton in the VUV Spectral Regions", Atomic Data and Nuclear Data Tables 18, 497 (1976).
- D,R R. W. B. Pearse and A. G. Gaydon, The Identification of Molecular Spectra, 3rd Edition (Wiley, New York, 1963).
- D,R R. D. Hudson and L. J. Kieffer, "Compilation of Atomic Ultraviolet Photoabsorption Cross Sections for Wavelengths between 3000 and 10 Å", Atomic Data 2, 205 (1971).
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- R E. C. Beaty and J. W. Gallagher, "Bibliography of Low-Energy Electron and Photon Cross Section Data", supplement (1975) to NBS Special Publication 426, JILA Information Center Report No. 15, Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, Colorado. ALSO: JILA Report No. 17, Supplement (1976) to NBS Special Publication 426.
- R J. W. Gallagher, "Bibliography of Free-Free Transitions in Atoms and Molecules", JILA Information Center Report No. 16, Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, Colorado (April, 1976).
- D W. F. Meggars, C. H. Corliss and B. Scribner, Tables of Spectral-Line Intensities, National Bureau of Standards Monograph No. 145 (1975).
- D,R S. N. Suchard, Ed., Spectroscopic Data, (IFI/Plenum, New York, 1975). Volume 1: Heteronuclear Diatomic Molecules, and Volume 2: Homonuclear Diatomic Molecules.
- D,R C. E. Moore, Atomic Energy Levels, in 3 volumes, Publication No. 35 of the National Standard Reference Data System of the National Bureau of Standards (1972).
- G. Herzberg, Spectra of Diatomic Molecules, (D. Van Nostrand Co., New York, 1950).
- D,R G. Bekefi (Ed.), Principles of Laser Plasmas, (Wiley, New York, 1976).
- D,R C.A. Brau, "Rare Gas-Halide Lasers", in C.K. Rhodes (Ed.). Eximer Lasers, Springer-Verlag, Berlin, 1978.

CONTENTS

D-1. ABSOLUTE CROSS SECTIONS FOR PHOTOIONIZATION FROM THE GROUND STATES

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Tabular Data D-1.1
Phototization Continuum Cross-Section for the Noble Gases
(Units of 10^{-18} cm^2)

Wavelength (Å)	Helium	Neon	Argon	Krypton	Xenon
400	4.98	8.91	21.0	15.1	6.38
410	5.21	8.86	22.7	16.5	7.26
420	5.45	8.80	24.3	17.8	8.24
430	5.69	8.72	25.7	19.2	9.13
440	5.93	8.64	27.1	20.6	10.0
450	6.18	8.54	28.3	21.9	11.0
460	6.43	8.42	29.5	23.2	12.0
470	6.68	8.29	30.5	24.5	13.0
480	6.94	8.15	31.4	25.8	14.0
490	7.19	8.00	32.3	27.0	15.1
500	7.46	7.83	33.1	28.2	16.2
510		7.66	33.8	29.3	17.4
520		7.47	34.4	30.4	18.4
530		7.26	34.9	31.4	20.0
540		7.05	35.4	32.4	21.4
550		6.82	35.7	33.3	23.1
560		6.58	36.1	34.2	24.7
570		6.33	36.3	35.0	26.2
580			36.5	35.7	27.9
590			36.7	36.4	29.4
600			36.7	37.1	30.8
610			36.8	37.7	32.5
620			36.7	38.3	33.9
630			36.6	38.8	35.2
640			36.5	39.3	36.8
650			36.3	39.8	38.4
660			36.1	40.2	39.6
670			35.8	40.6	41.0
680			35.5	41.0	42.3
690			35.1	41.4	43.7
700			34.7	41.7	44.9
710			34.2	42.0	46.1
720			33.7	42.2	47.3
730			33.1	42.5	48.4
740			32.5	42.7	49.4
750			31.8	42.8	50.4
760			31.1	42.9	51.4
770			30.3	42.9	52.4
780			29.5	42.8	53.4
790				42.6	54.3

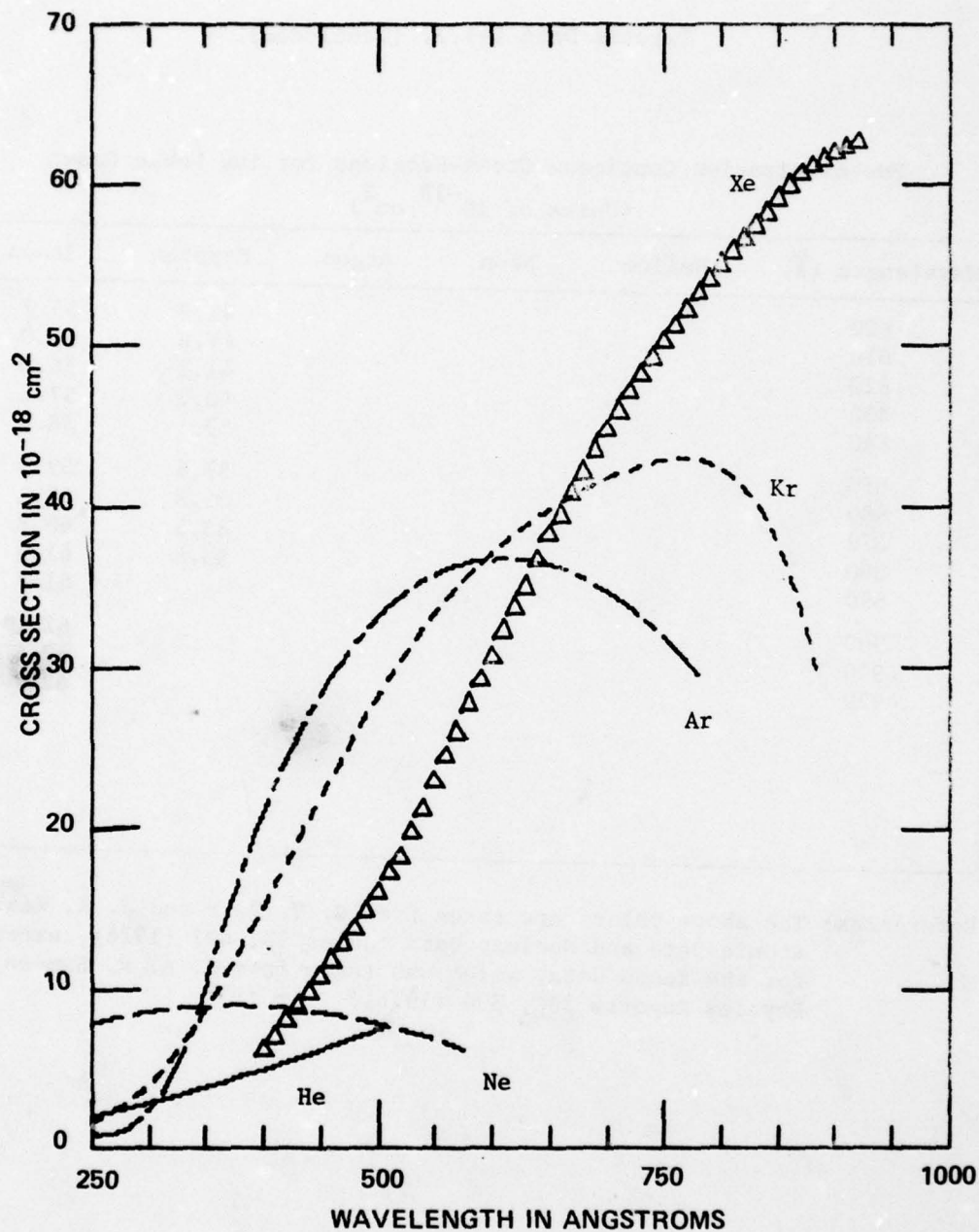
(Continued next page)

Tabular Data D-1.1. (Concluded).

Photoionization Continuum Cross-Sections for the Noble Gases
(Units of 10^{-18} cm^2)

Wavelength (\AA)	Helium	Neon	Argon	Krypton	Xenon
800				42.3	55.2
810				41.8	56.0
820				41.2	56.8
830				40.2	57.6
840				39.1	58.4
850				37.6	59.3
860				35.8	60.1
870				33.5	60.8
880				30.8	61.3
890					61.7
900					62.1
910					62.4
920					62.7

References: The above values are taken from G. V. Marr and J. B. West, Atomic Data and Nuclear Data Tables 18, 497 (1976), except for the Xenon data, which was taken from J. A. R. Samson, Physics Reports 28C, 304 (1976).



Photoionization cross section of He, Ne, Ar, Kr, and Xe gases from 250-1000 Å. The values were taken from the preceding table.

Graphical Data D-1.2.

Comments and Further References

The data tabulated are for the continuum cross section only; resonances are not included. There are many such resonances (several hundred in the case of xenon, for example). Studies of resonances and of autoionizing states are to be found as follows:

He ($\lambda < 250 \text{ \AA}$); R. P. Madden and K. Codling, *Astrophys. J.* 141, 364 (1965).

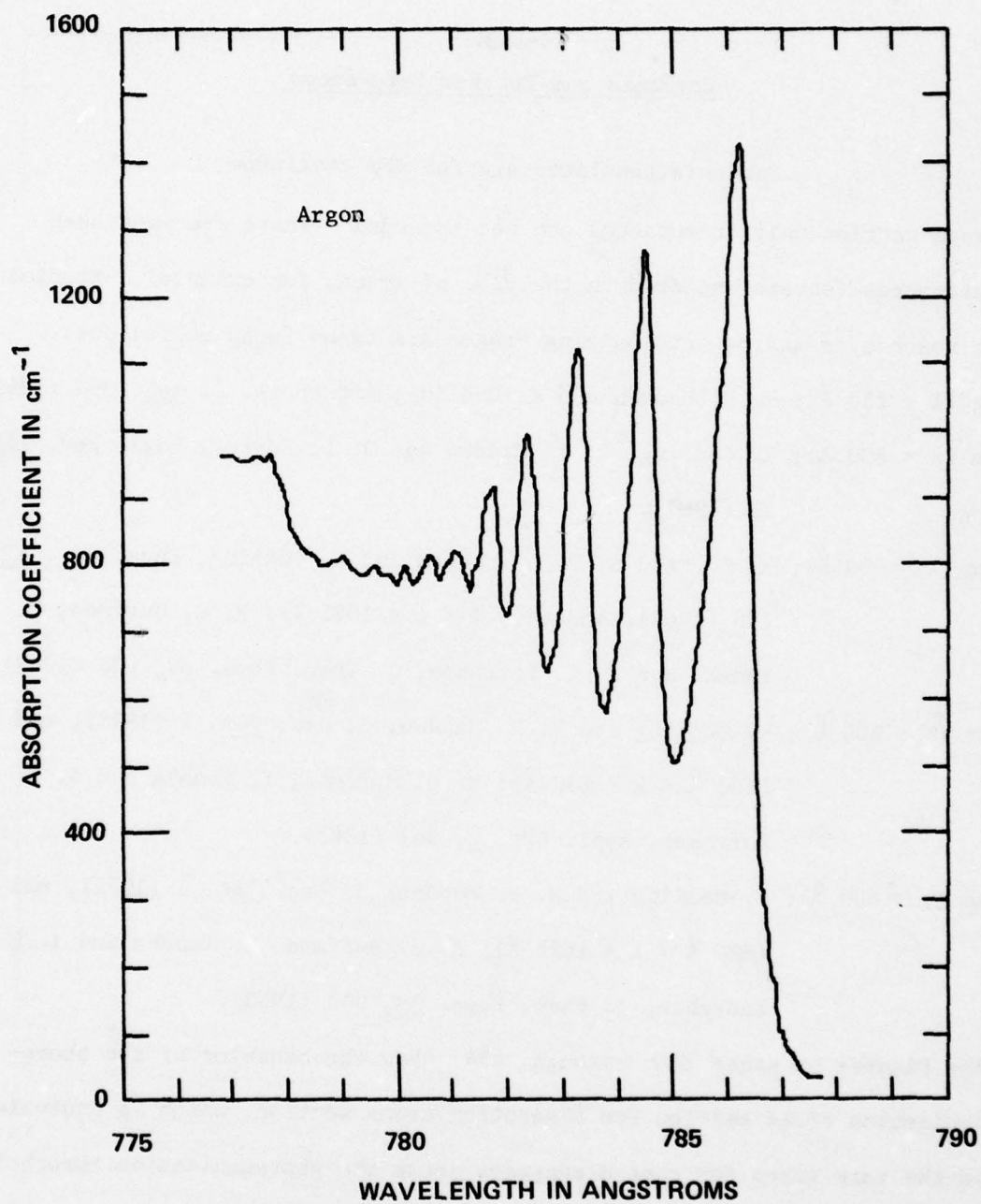
Ne ($\lambda < 600 \text{ \AA}$); K. Codling, R. P. Madden and D. L. Ederer, *Phys. Rev.* 155 26 (1967).

Ar ($\lambda < 600 \text{ \AA}$); R. P. Madden, D. L. Ederer and K. Codling, *Phys. Rev.* 177, 136 (1969), and ($600 \text{ \AA} < \lambda < 1025 \text{ \AA}$); R. E. Huffman, Y. Tanaka and J. C. Larrabee, *J. Chem. Phys.* 39, 902 (1963).

Kr ($\lambda < 600 \text{ \AA}$); K. Codling and R. P. Madden, *J. Res.* 76A, 1 (1972), and ($600 \text{ \AA} < \lambda < 890 \text{ \AA}$); R. E. Huffman, Y. Tanaka and J. C. Larrabee, *Appl. Opt.* 2, 947 (1963).

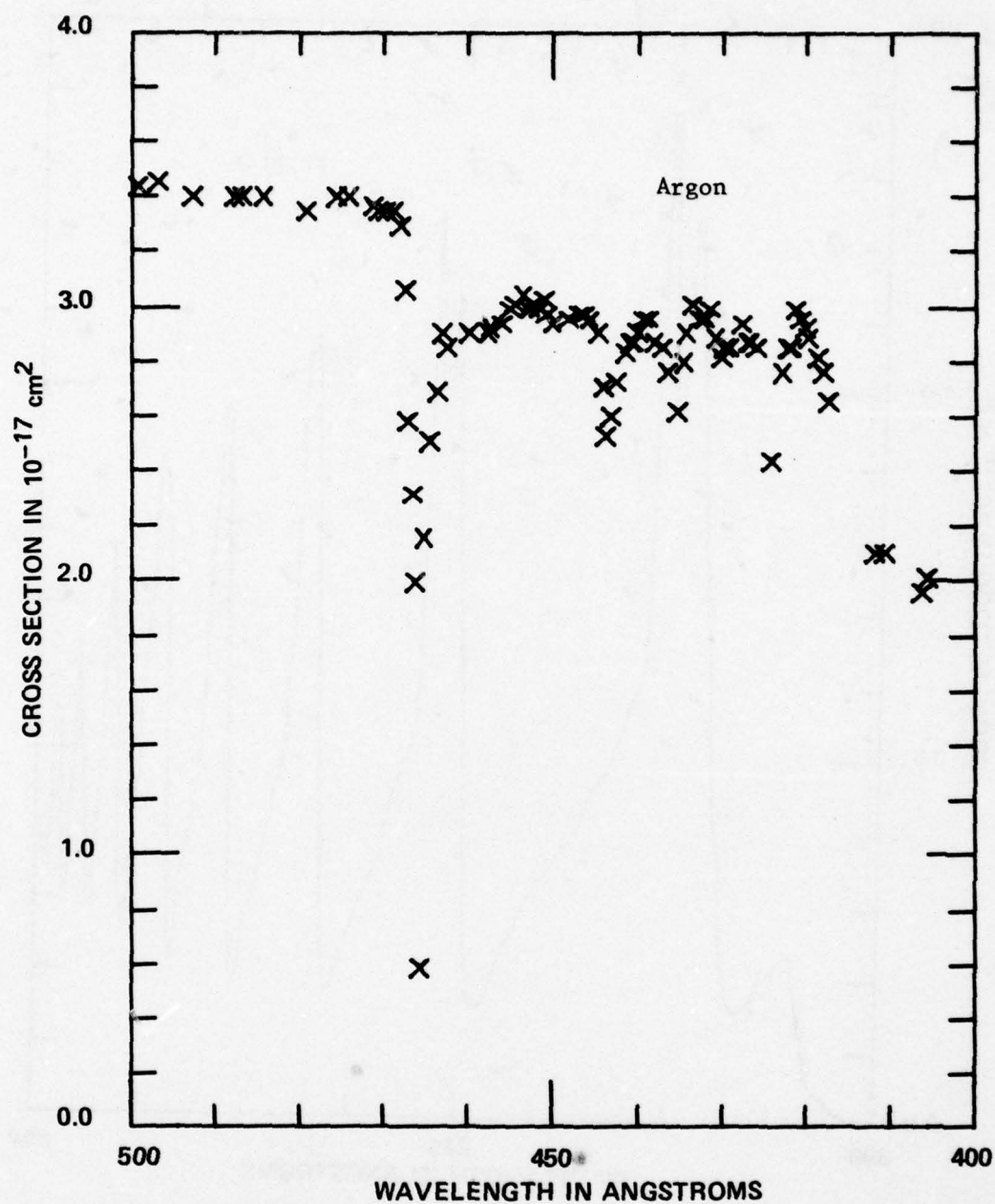
Xe ($\lambda < 600 \text{ \AA}$); K. Codling and R. P. Madden, *J. Res.* 76A, 1 (1972), and ($600 \text{ \AA} < \lambda < 1025 \text{ \AA}$); R. E. Huffman, Y. Tanaka and J. C. Larrabee, *J. Chem. Phys.* 39, 902 (1963).

The Figures on pages 649 through 654 show the behavior of the photoionization cross section (or absorption cross section, which is equivalent in the rare gases for photon energies above the photoionization threshold) for Ar, Kr and Xe in regions where sharp structure exists.



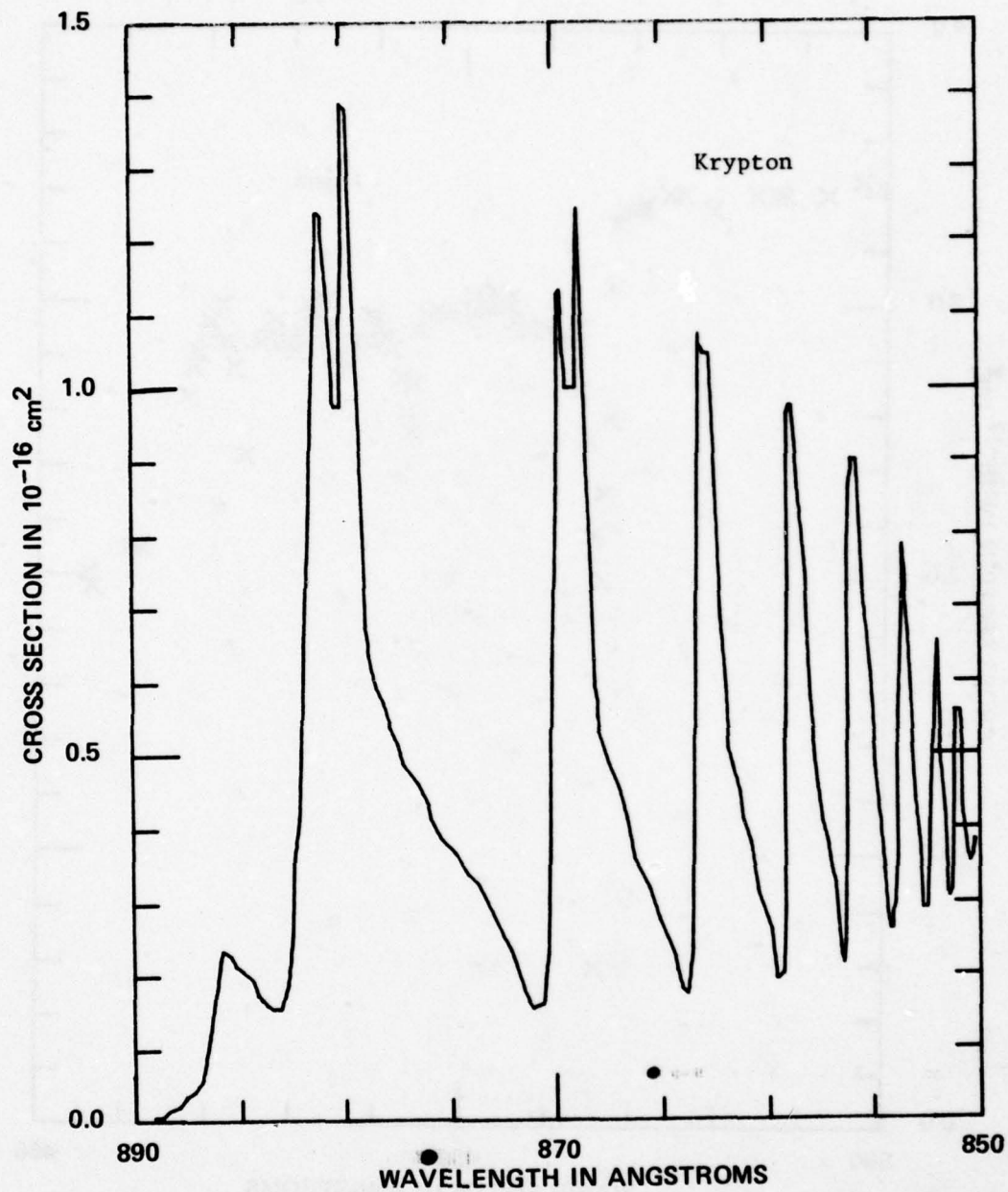
Absorption coefficient of argon showing structure due to autoionization; taken from R. E. Huffman, Y. Tanaka, and J. C. Larrabee, J. Chem. Phys. 39, 902 (1963).

Graphical Data D-1.4.



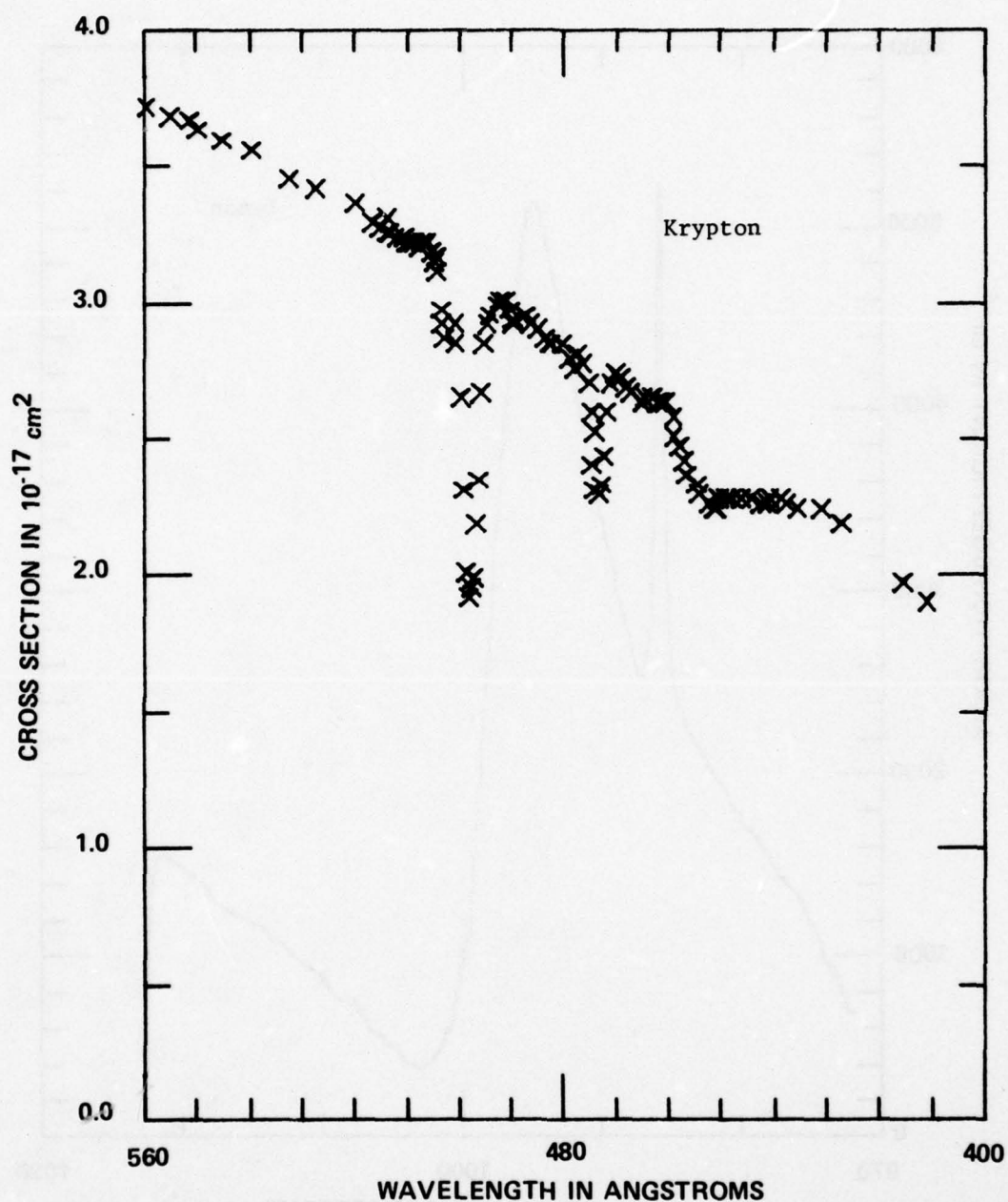
Photoionization cross section for argon from 400-500 Å. Taken from R. D. Hudson and L. J. Kieffer, Atomic Data 2, 202 (1971); the data is originally from J. A. R. Samson, J. Opt. Soc. Am. 54, 420 (1964).

Graphical Data D-1.5.



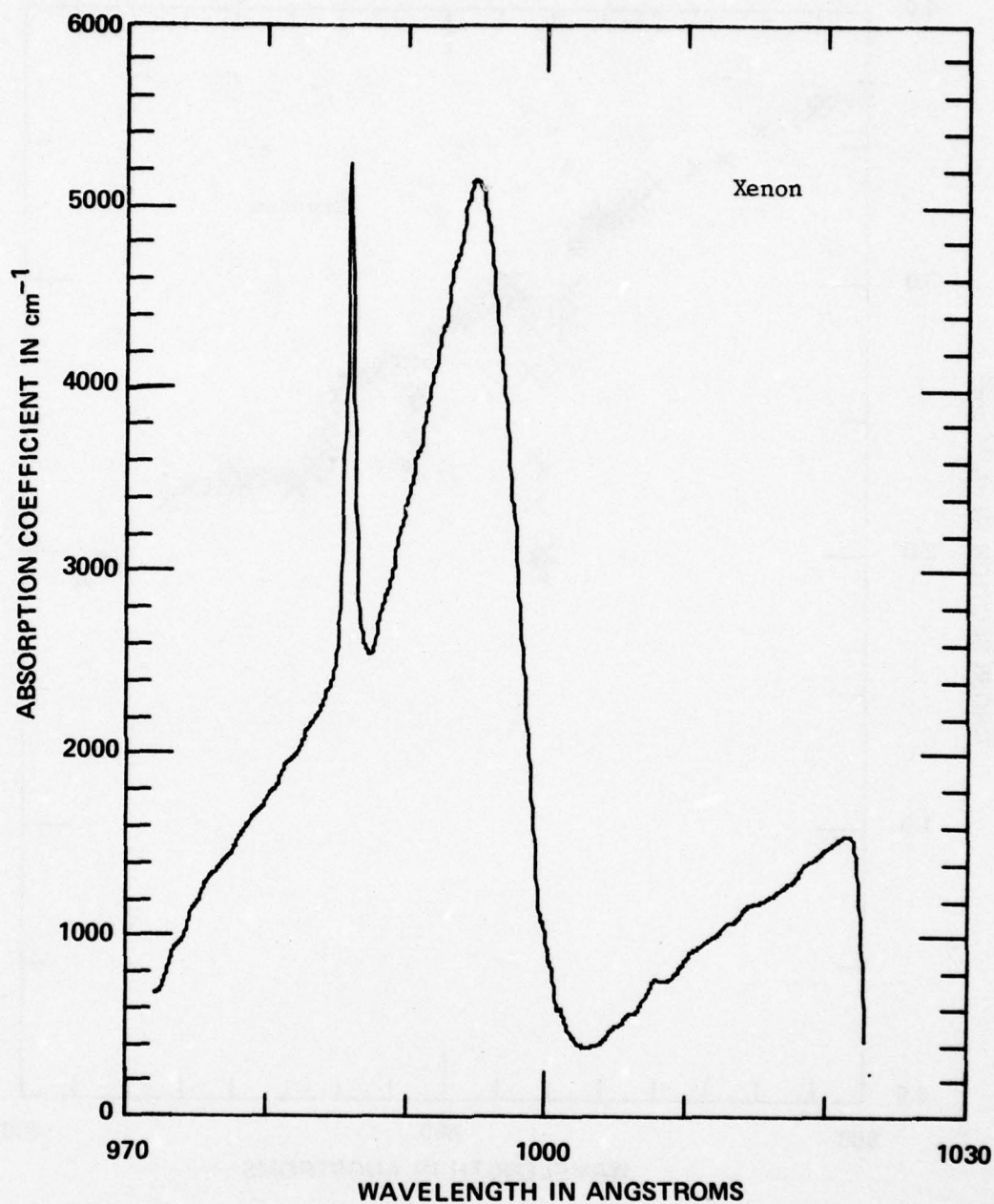
Total absorption cross section of krypton from 850-890 Å. Taken from R. D. Hudson and L. J. Kieffer, Atomic Data 2, 202 (1971); the data is originally from R. E. Huffman, Y. Tanaka, and J. C. Larrabee, Appl. Opt. 2, 947 (1963).

Graphical Data D-1.6.



Total absorption cross section of krypton from 400-560 Å. Taken from R. D. Hudson and L. J. Kieffer, Atomic Data 2, 202 (1971); the original data is from J. A. R. Samson, Phys. Rev. 132, 2122 (1963).

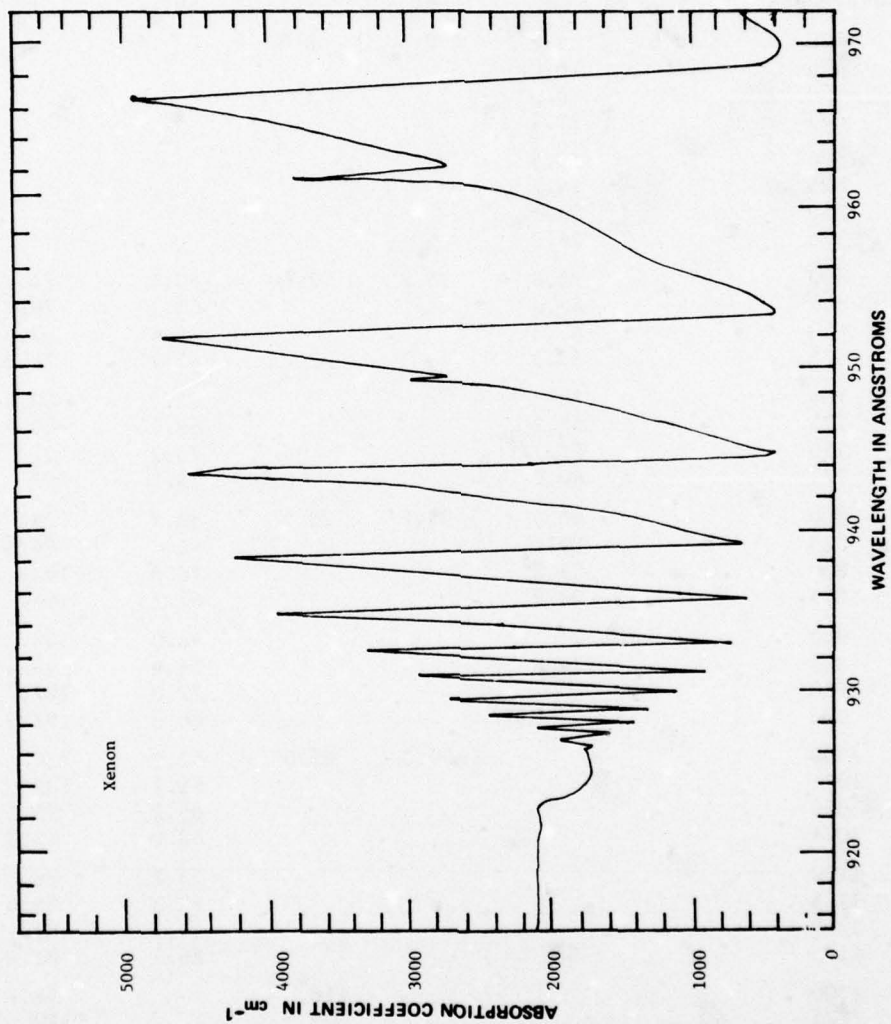
Graphical Data D-1.7.



Total absorption coefficient of xenon from 970-1030 Å. Taken from
R. E. Huffman, Y. Tanaka, and J. C. Larrabee, J. Chem. Phys. 39,
902 (1963).

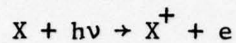
Graphical Data D-1.8.

Total absorption coefficient of xenon from 916-972 Å. Taken from R.E. Huffman, Y. Tanaka, and J.C. Larrabee, J. Chem. Phys. 39, 902 (1963).



Graphical Data D-1.9.

Tabular Data D-1.10.
Photoionization Cross-Sections of Halogen Atoms and Molecules



X = F, Cl, Br, I, Br₂, I₂

Wavelength in Angstroms, Cross-Section in 10 ⁻¹⁸ cm ²						
Wavelength	F	Cl	Br	I	Br ₂	I ₂
400	10.6	4.6	2.5	2.07		
425		6.0				
450		8.3				
475		11.4				
500		15.5				
525		19.8				
550		23.7				
575		28.8				
600		34.8	15.2	7.60	63.1	74.2
625		40.0			63.1	70.7
650		45.8			63.4	67.3
675		52.3			63.7	74.2
700		58.3			66.9	80.4
725		63.2			69.7	89.7
750		67.1			73.2	101.
775		60.2			75.2	107.
800		60.5	34.0	23.5	80.7	103.
825		59.8			76.4	96.6
850		59.2			70.9	107.
875		28.8			67.1	106.
900		27.7			66.0	108.
925		26.8			64.0	90.4
950					72.0	107.
975					66.3	92.5
1000			60.0	65.0	57.9	114.
1025					61.7	103.
1050					65.7	95.6
1075					68.0	73.8
1100					73.2	86.3
1125					53.3	96.6
1150					40.3	82.1
1175					26.5	81.1
1200				116.*		98.7
1225						122.
1250						109.
1275						123.
1300						61.1
1325						73.8

D-1.11.

Photoionization Cross-Sections of Halogen Atoms and Molecules

References and Comments:

*This number was badly printed in the journal, and may be incorrect.

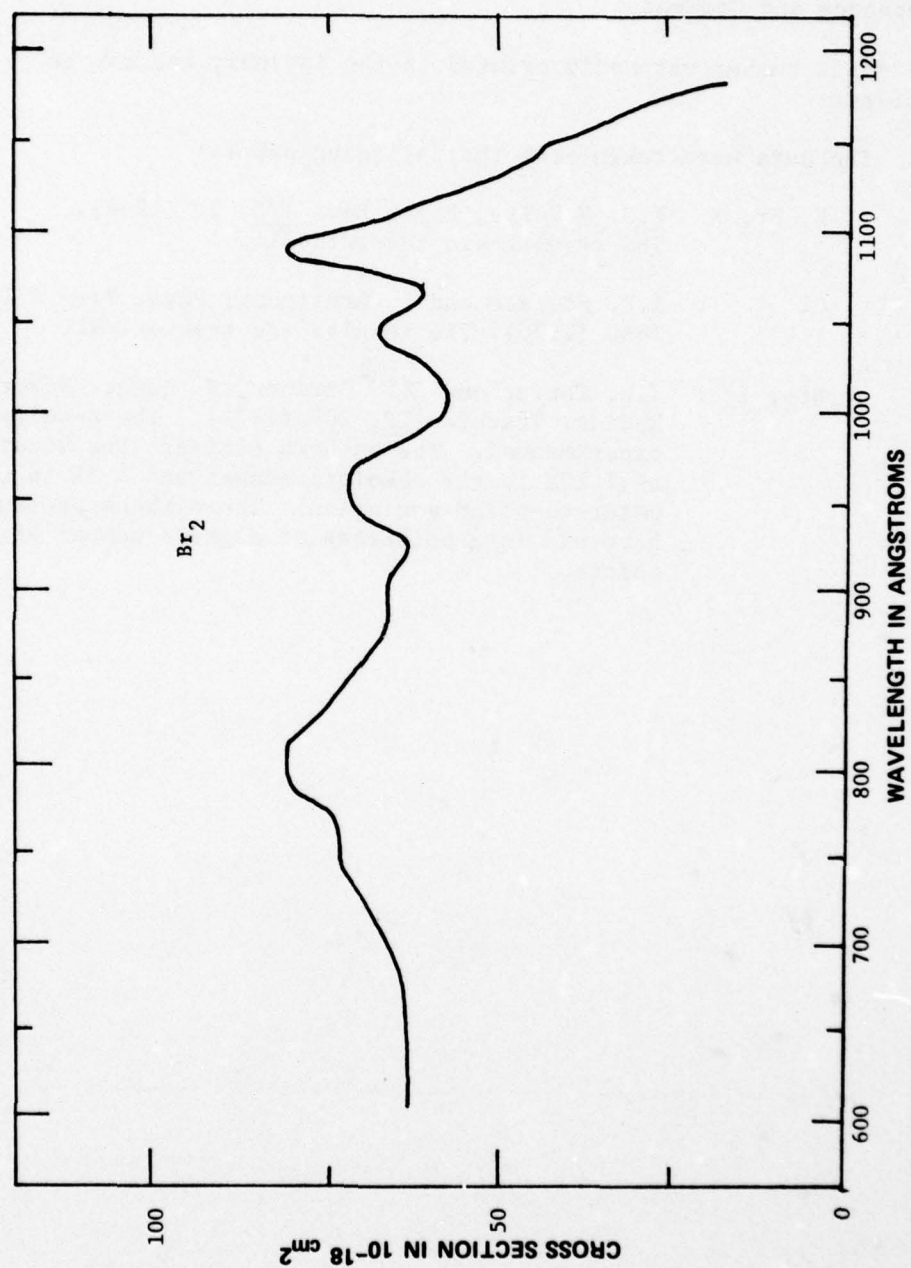
The data were taken from the following papers:

F, Br, I: E.J. McGuire, Phys. Rev. 175, 20 (1968).
The results are theoretical.

Cl : A.F. Starace and L. Armstrong, Phys. Rev. A 13,
1850 (1976). The results are theoretical.

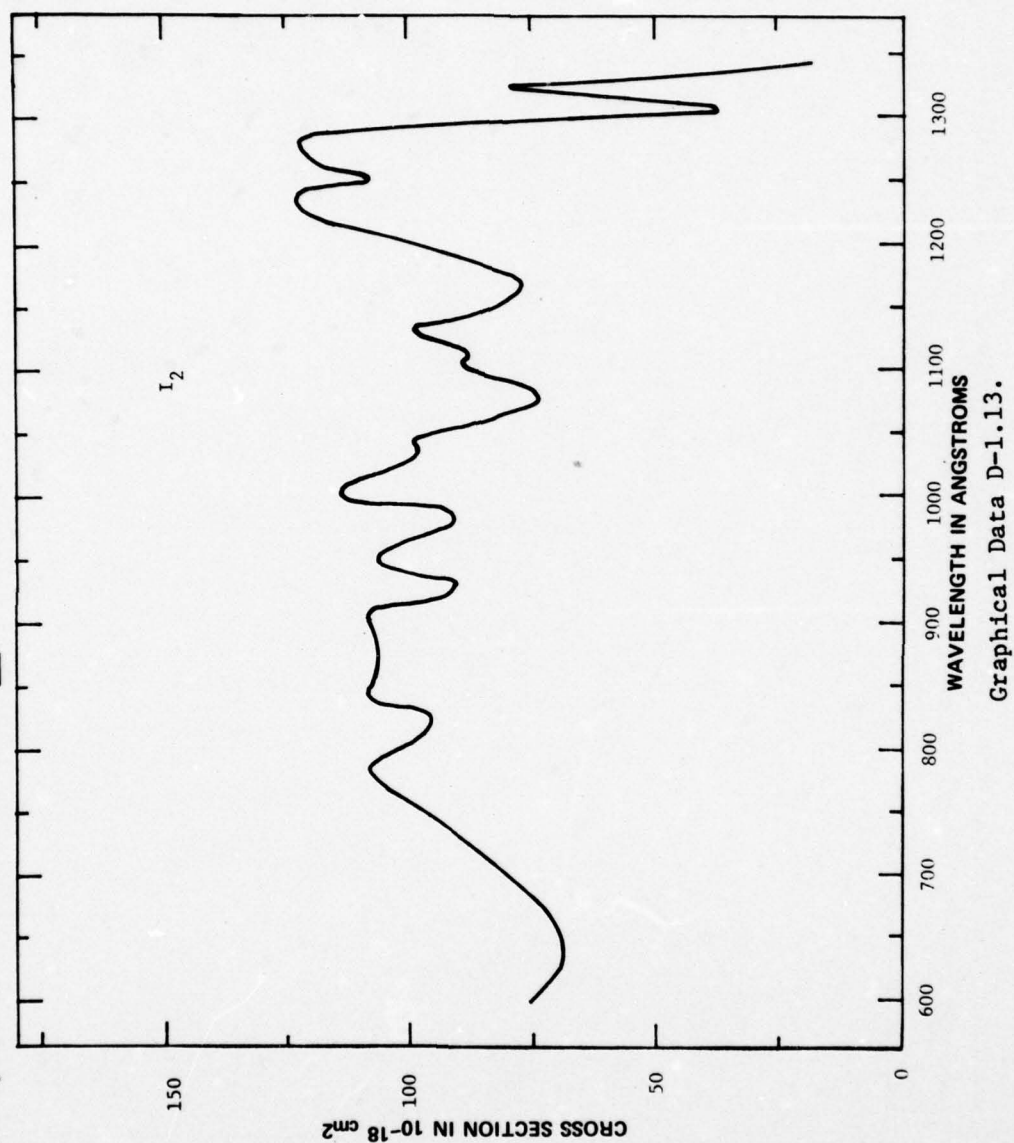
Br₂, I₂ : J.H. Carver and J.L. Gardner, J. Quant. Spectrosc.
Radiat. Transfer 12, 207 (1972). The results are
experimental. The authors estimate the accuracy
as $\pm 15\%$ in the absolute number and $\pm 5\%$ in the
point-to-point variation. The numbers presented
here are interpolations of a great number of data
points.

Photoionization cross section for Br₂ from 600-1200 Å. Taken from J. H. Carver and J. L. Gardner, J. Quant. Spectrosc. Radiat. Transfer 12, 207 (1972).



Graphical Data D-1.12.

Photolonization cross section for I_2 from 600-1340 Å. Taken from J. H. Carver and J. L. Gardner, J. Quant. Spectrosc. Radiat. Transfer 12, 207 (1972).



D-2. ABSOLUTE CROSS SECTIONS FOR PHOTOIONIZATION FROM EXCITED STATES

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Tabular Data D-2.1.

Photoionization Cross-Sections for Metastable Rare Gas Atoms

Wavelength is in Angstroms, Cross-Sections are in units of 10^{-20} cm^2					
Wavelength	He(2^3S)	Ne*	Ar*	Kr*	Xe*
500	39.	9.75	4.89	2.41	2.17
600	57.	11.9	5.95	2.75	2.44
700	77.	13.8	6.97	3.04	2.78
800	99.	15.3	7.88	3.28	2.97
900	123.	16.5	8.66	3.44	3.16
1000	149.	17.2	9.31	3.51	3.40
1100	176.	17.4	9.79	3.49	3.54
1200	209.	17.1	10.1	3.38	3.57
1300	231.	16.4	10.2	3.18	3.54
1400	260.	15.2	10.1	2.88	3.48
1500	287.	13.7	9.74	2.52	3.36
1600	310.	11.9	9.22	2.08	3.13
1700	329.	9.84	8.51	1.61	2.80
1800	341.	7.71	7.64	1.14	2.40
1900	366.	5.60	6.63	0.684	1.95
2000	389.	3.60	5.54	0.308	1.49
2100	412.	1.89	4.41	0.065	1.06
2200	434.	0.661	3.27	0.006	0.676
2300	454.	0.040	2.18	0.200	0.346
2400	473.	0.224	1.23	0.736	0.102
2500	490.	1.44	0.507	1.70	0.000
2600			0.085	3.12	0.097
2700			0.034	5.15	0.456
2800			0.478	7.94	1.12
2900			1.61	11.6	2.29
3000				16.5	3.89
3100					6.23
3200					9.38

References and Comments: The above table is the result of theoretical calculations, taken from the following sources:

He(2^3S): V. L. Jacobs, Phys. Rev. A 9, 1938 (1974); and K. J. McCann and M. R. Flannery, Appl. Phys. Lett. 31, 599 (1977).

Values for the 2^1S , 2^1P and 2^3P states are available in Jacobs; the results lie in the $1.0\text{--}5.0 \times 10^{-18} \text{ cm}^2$ range.

General Information D-2.2.

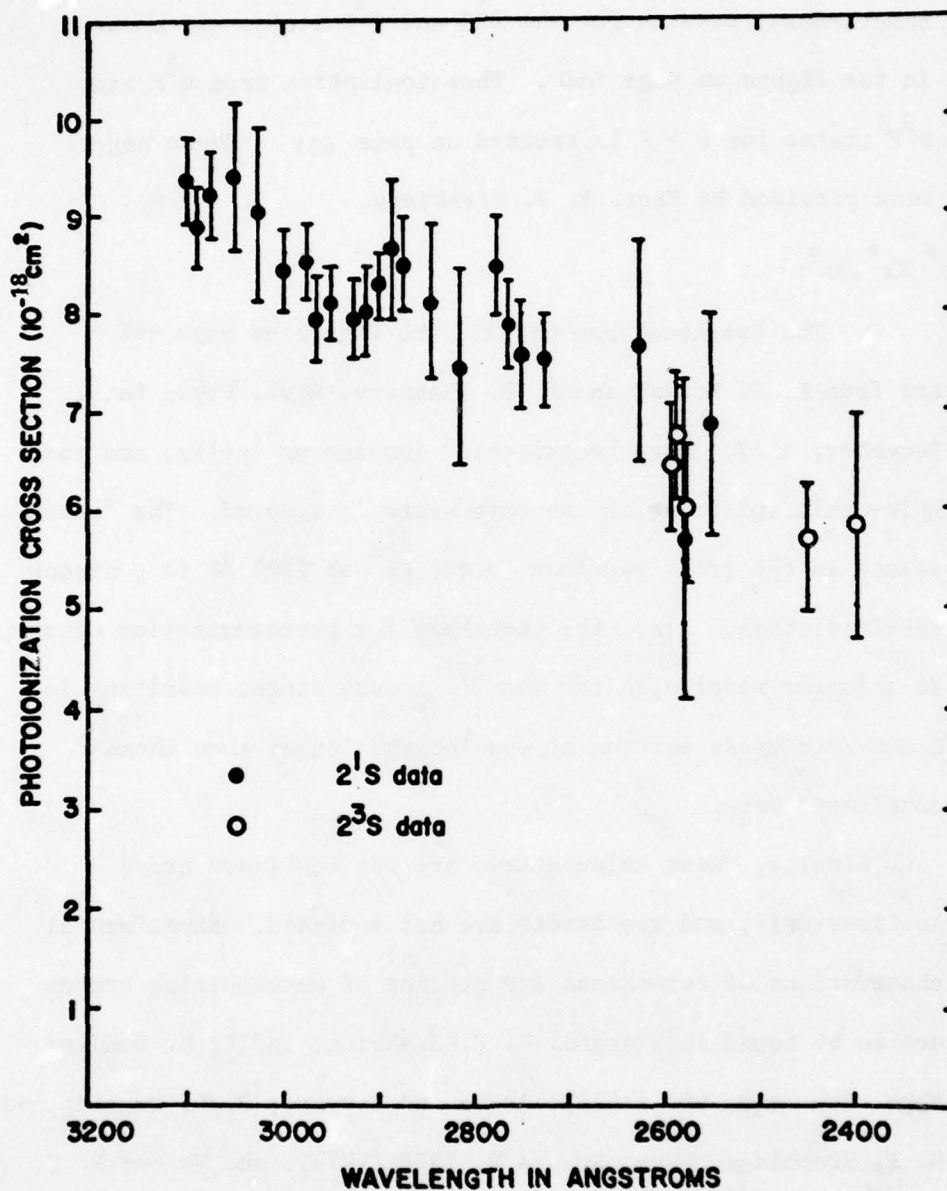
Experimental results for the 2^1S and 2^3S states are shown in the Figure on page 660. Photoionization from n^1P and n^3P states for $n > 2$ is treated on page 661. These pages were provided by Prof. R. F. Stebbings.

Ne^{*}, Ar^{*}, Kr^{*}, Xe^{*}:

The tabulated numbers and the Figure on page 662 are from K. J. McCann and M. R. Flannery, Appl. Phys. Lett., December, 1977. Here "metastable" implies $np^5(n+1)s$, and the spin-orbit splitting of the core state is ignored. The "zero" values in the cross sections (e.g., Xe^{*} at 2500 Å) is a direct result of this. Also, the threshold for photoionization occurs at a longer wavelength for the $^2P_{1/2}$ core state, resulting in a non-zero cross section at wavelengths longer than those considered here.

Finally, these calculations are for continuum cross sections only, and resonances are not included. Experimental observations of resonances and studies of autoionizing states are to be found in: Argon; R. F. Stebbings and F. B. Dunning, Phys. Rev. A 8, 665 (1973), Argon and Krypton; F. B. Dunning and R. F. Stebbings, Phys. Rev. A 9, 2378 (1974), and Xenon; R. D. Rundel, F. B. Dunning, H. C. Goldwire and R. F. Stebbings, J. Opt. Soc. Am. 65, 628 (1975). Figures exhibiting the observed structure (kindly provided by the authors) are on pages 663 through 666.

Photoionization of Helium Metastable Atoms*



* R. F. Stebbings, F. B. Dunning, F. K. Tittel, and R. D. Rundel, Phys. Rev. Lett. **30**, 815 (1973)

Graphical Data D-2.3.

Tabular Data D-2.4.

Photoionization of He($n^1,^3P$) Atoms*

A. Triplet System

n	Wavelength (Å)	Cross section (cm ²)
3	3888.6	$(8.7 \pm 2.0) \times 10^{-18}$
4	3187.7	$(2.1 \pm 0.4) \times 10^{-18}$
5	2945.1	$(8.6 \pm 1.8) \times 10^{-19}$

B. Singlet System

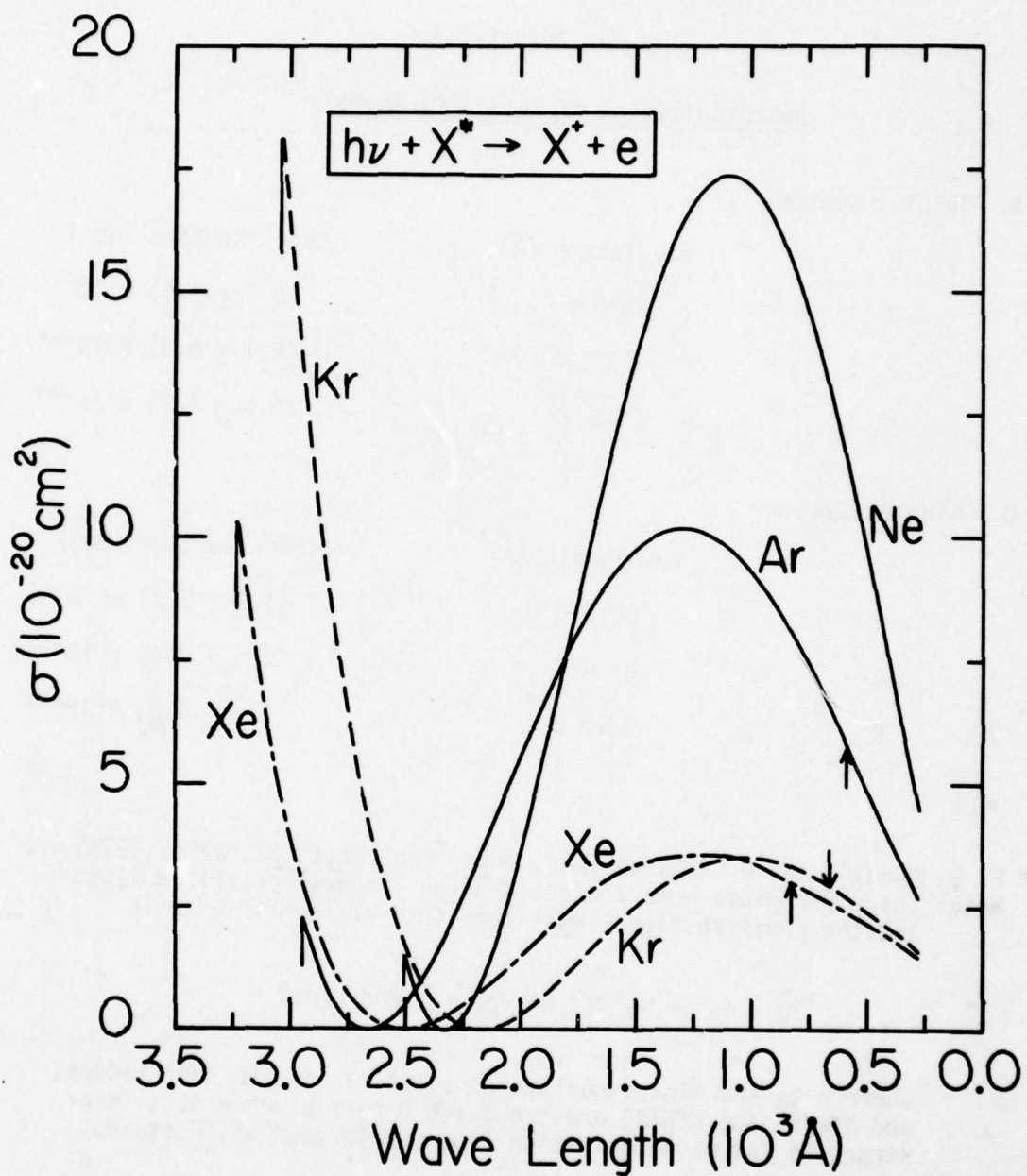
n	Wavelength (Å)	Cross section (cm ²)
3	5015.6	$(1.0 \pm 0.2) \times 10^{-17}$
4	3964.7	$(2.2 \pm 0.4) \times 10^{-18}$
5	3613.6	$(8.8 \pm 1.8) \times 10^{-19}$

* F. B. Dunning and R. F. Stebbings, Phys. Rev. Lett. **32**, 1286 (1974).

Note: The experiments were conducted using linearly polarized light and the cross section Q must therefore be identified with

$$Q = 4\pi^2 \alpha a_0^2 (3 df_S/dE + 1.2 df_D/dE)$$

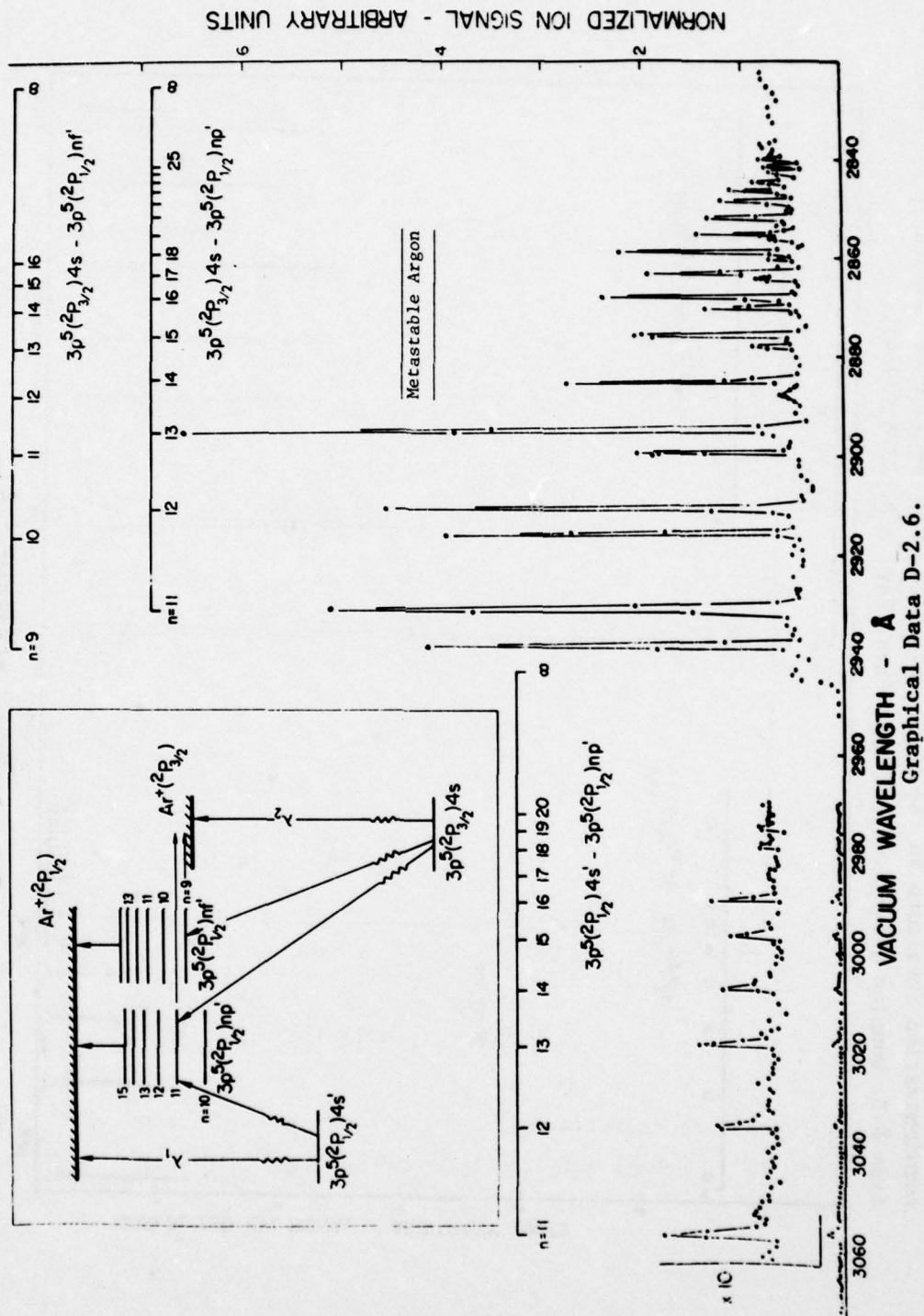
where α is the fine structure constant, a_0 is the Bohr radius, and df_S/dE and df_D/dE are the S and D partial-wave oscillator strengths for photoionization from unpolarized $n^1,^3P$ states.



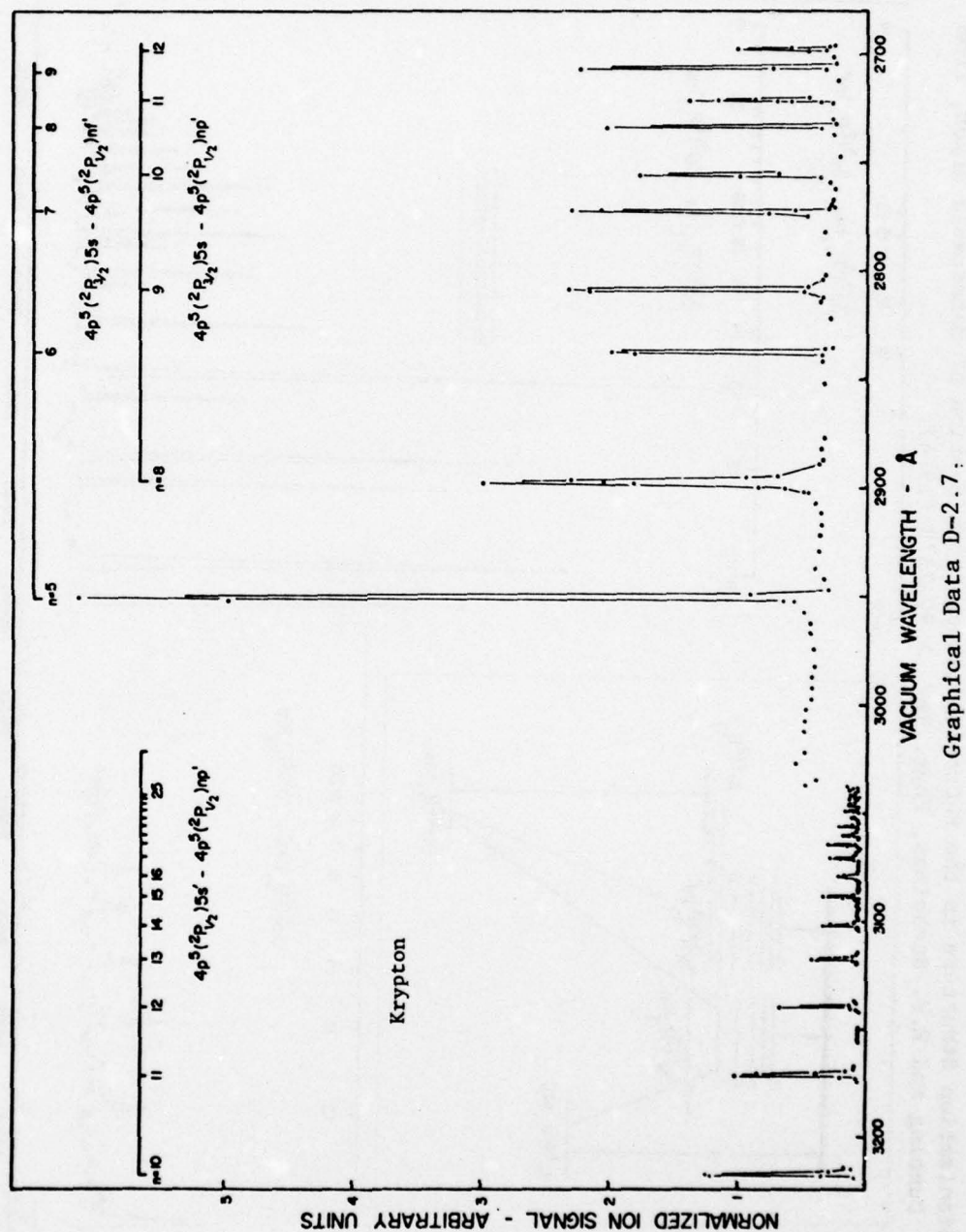
Photoionization cross sections for metastable atoms Ne^* , Ar^* , Kr^* and Xe^* .
 Taken from K. J. McCann and M. R. Flannery, Appl. Phys. Lett., Dec. 1977.

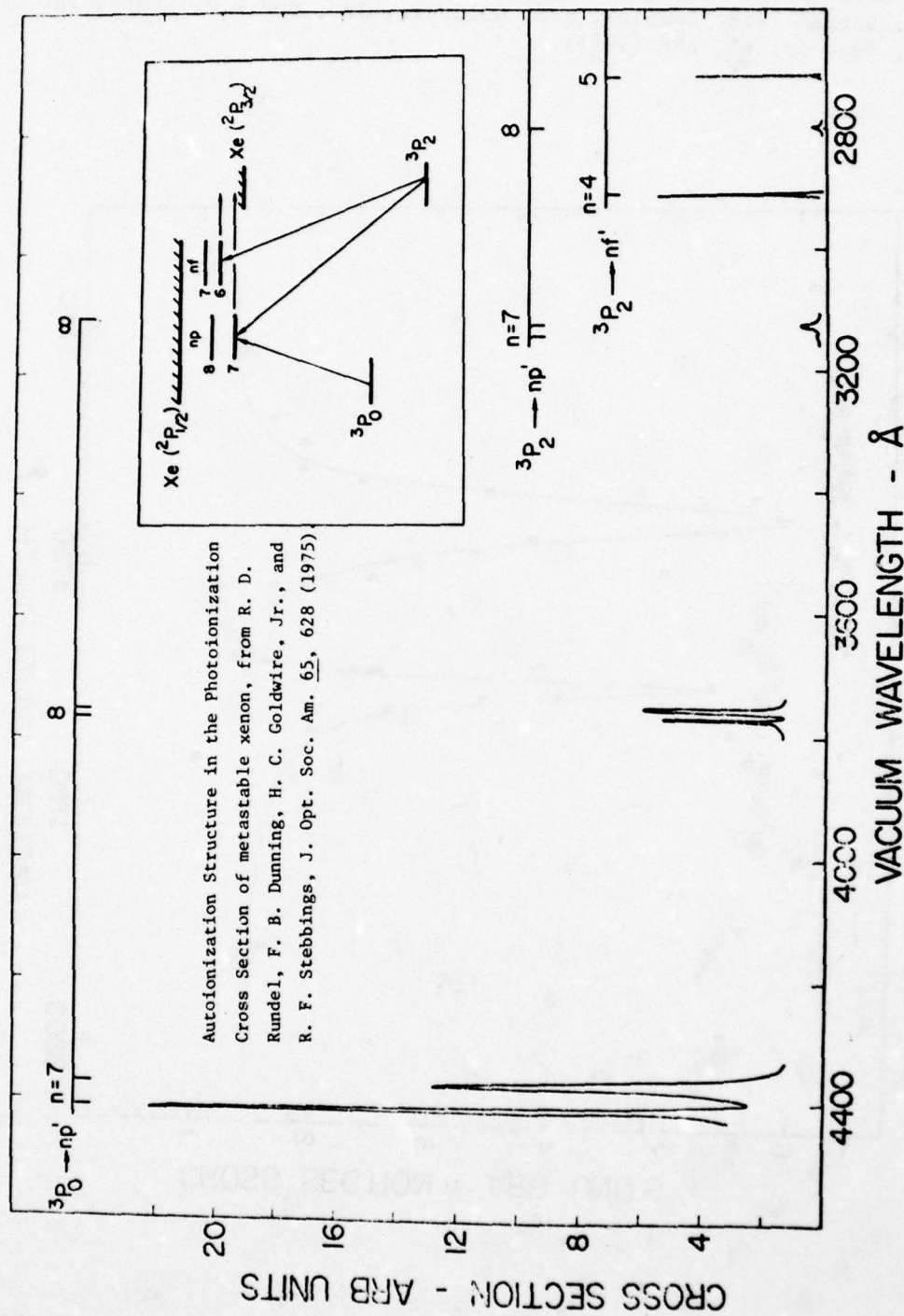
Graphical Data D-2.5

Autoionization Structure in the Photo-Ionization Cross Section of Metastable Argon, from F.B. Dunning and R.F. Stebbings, Phys. Rev. A 9, 2378 (1974).



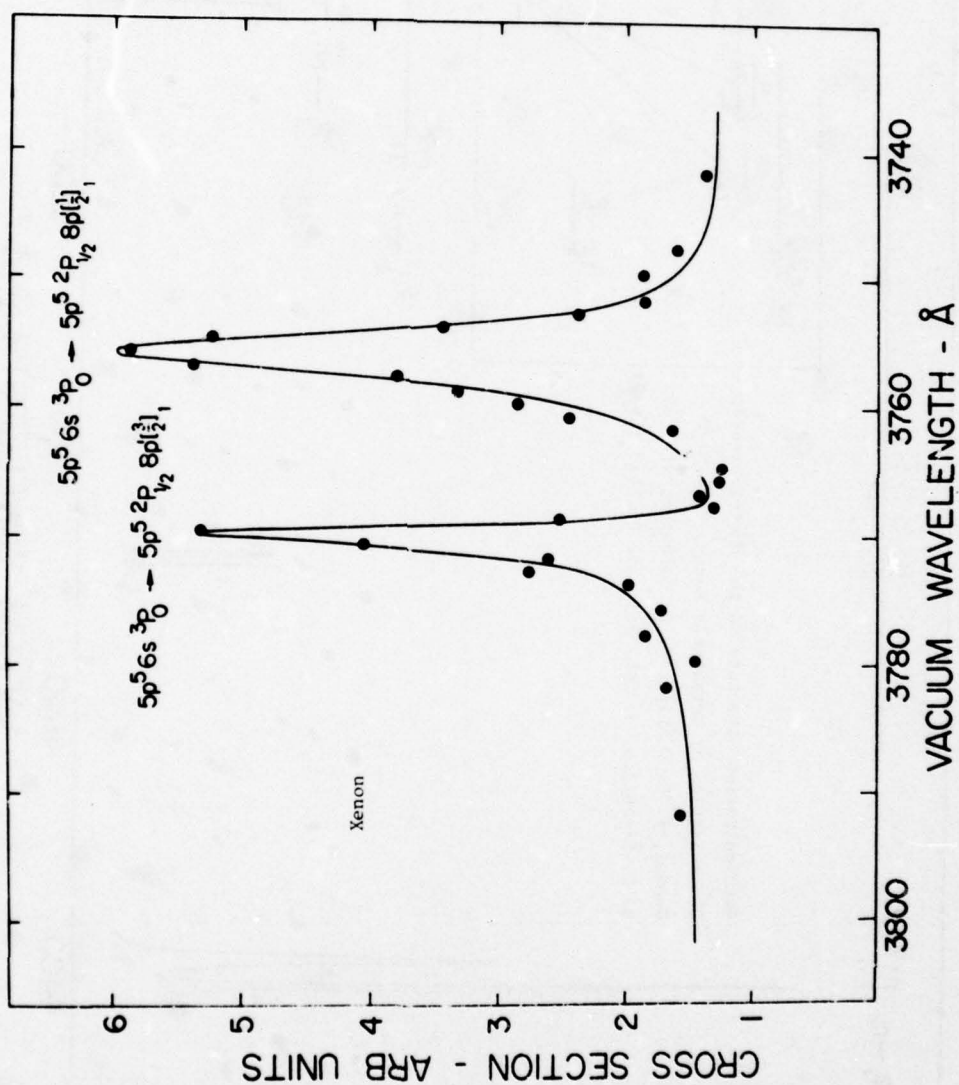
Autoionization Structure in the Photoionization Cross Section of Metastable Krypton,
from F.B. Dunning and R.F. Stebbings, Phys. Rev. A 9, 2378 (1974).





Graphical Data D-2.8.

Structure in the photoionization of metastable xenon showing experimental data (points) and theoretical fitted Fano profile (curve), from R.D. Rundel, F.B. Dunning, H.C. Goldwire, Jr., and R.F. Stebbings, J. Opt. Soc. Am. 65, 628 (1975).



Graphical Data D-2.9.

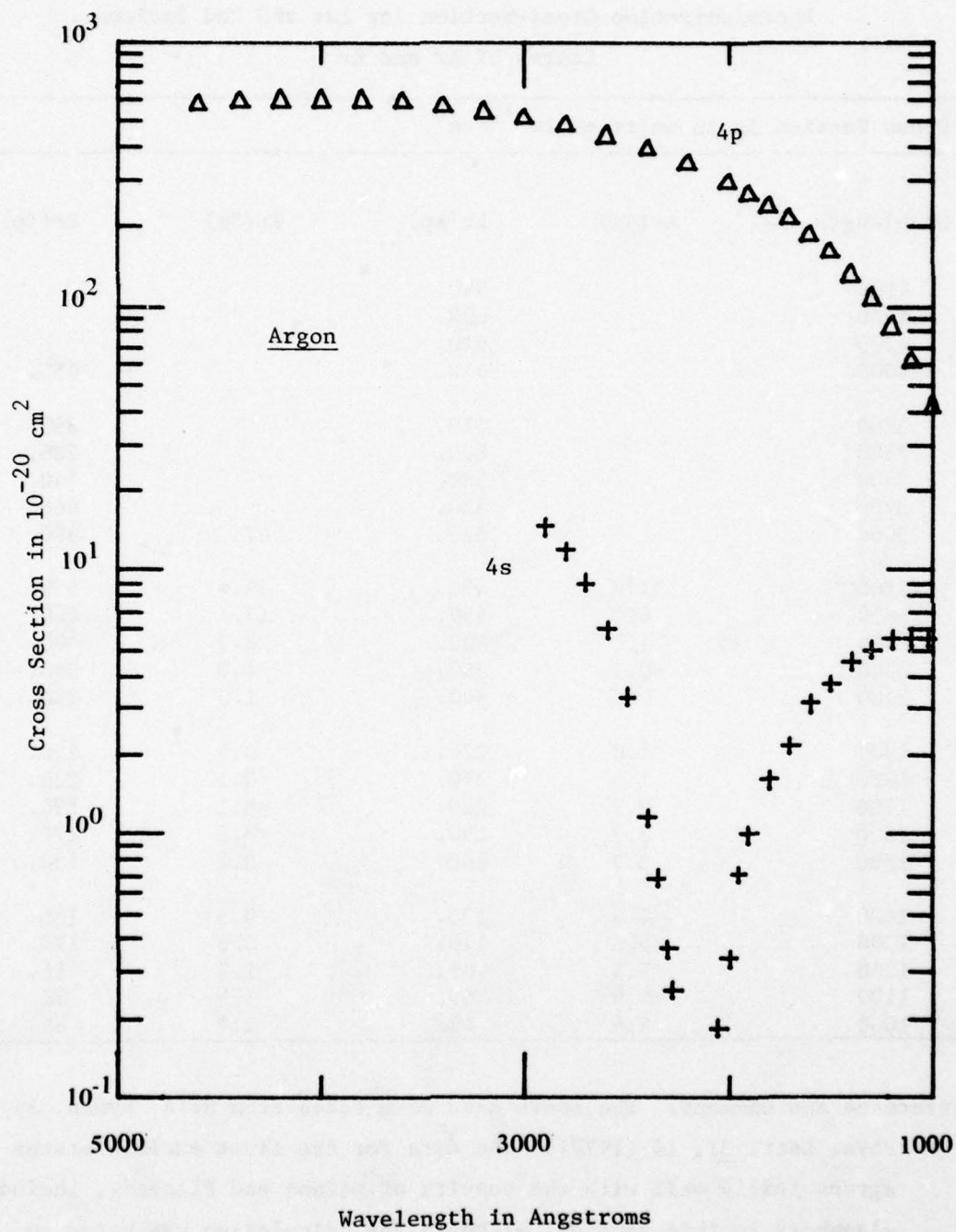
Tabular Data D-2.10.

Photoionization Cross-Section for 1st and 2nd Excited
States of Ar and Kr

Cross Section is in units of 10^{-20} cm^2 .				
Wavelength (Å)	Ar(4s)	Ar(4p)	Kr(5s)	Kr(5p)
4600		590.		
4400		600.		
4200		610.		
4000		610.		980.
3800		610.		890.
3600		600.		780.
3400		580.		740.
3200		550.		660.
3000		520.	47.	590.
2800	11.8	490.	31.	530.
2600	6.0	450.	17.	460.
2400	1.2	400.	8.9	400.
2200	<0.1	350.	4.0	340.
2000	0.3	300.	1.0	280.
1900	1.0	270.	0.5	250.
1800	1.6	240.	<0.1	220.
1700	2.2	220.	<0.1	190.
1600	3.1	190.	<0.1	170.
1500	3.7	160.	0.2	150.
1400	4.5	130.	0.5	130.
1300	5.0	110.	0.8	110.
1200	5.5	85.	1.2	86.
1100	5.6	63.	1.5	71.
1000	5.6	43.	1.7	54.

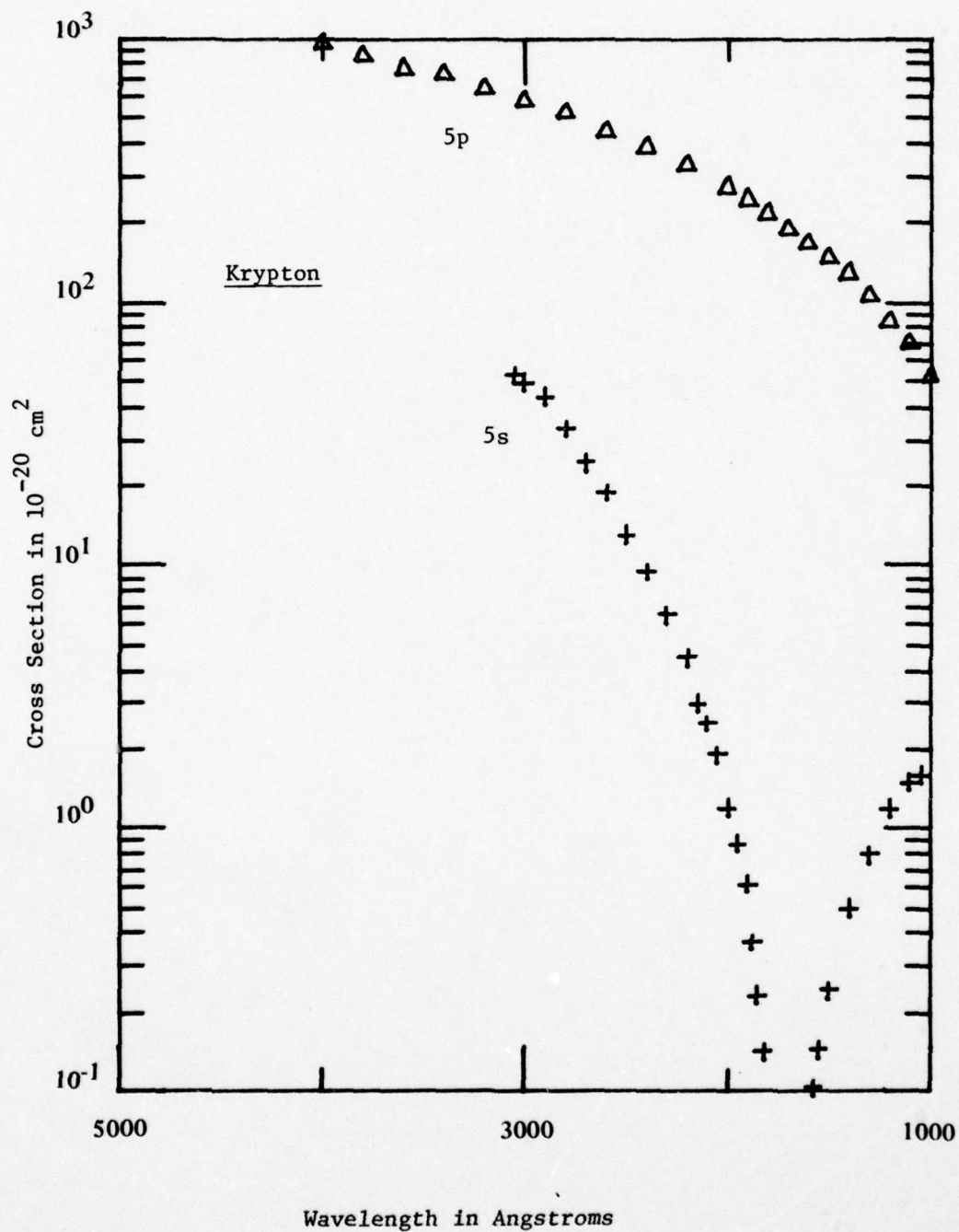
Reference and Comment: The above data were taken from H. A. Hyman, Appl. Phys. Lett. 31, 14 (1977). The data for the first excited states agrees fairly well with the results of McCann and Flannery, included elsewhere in this section, although the calculation was based on a slightly different approach.

Graphical Data D-2.11.



Photoionization Cross Section for the first two excited states of argon, taken from H. A. Hyman, Appl. Phys. Lett. 31, 14 (1977).

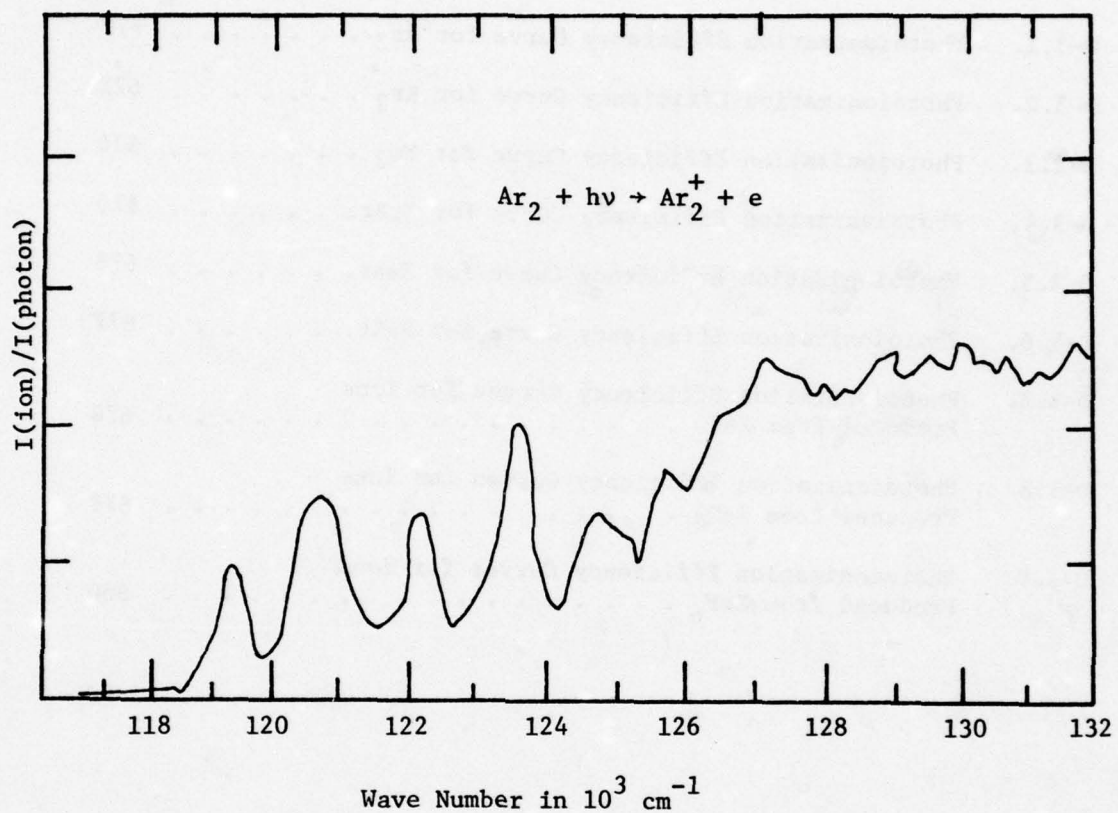
Graphical Data D-2.12.



Photoionization Cross Section for the first two excited states of krypton, taken from H. A. Hyman, Appl. Phys. Lett. 31, 14 (1977).

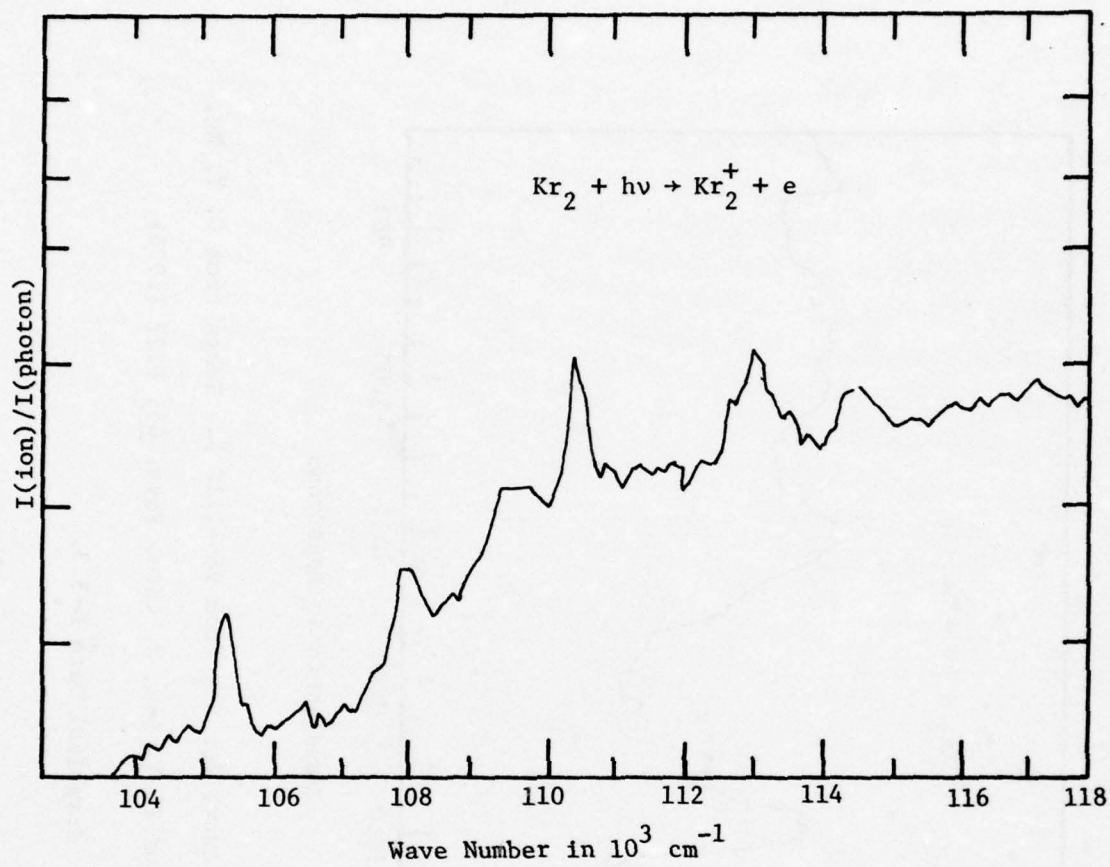
D-3. RELATIVE PHOTOIONIZATION CROSS SECTIONS
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Photoionization efficiency curve for Ar_2^+ from 117,000-132,000 cm^{-1} .
Taken from C. Y. Ng, D. J. Trevor, B. H. Mahan and Y. T. Lee, J. Chem.
Phys. 66, 446 (1977).

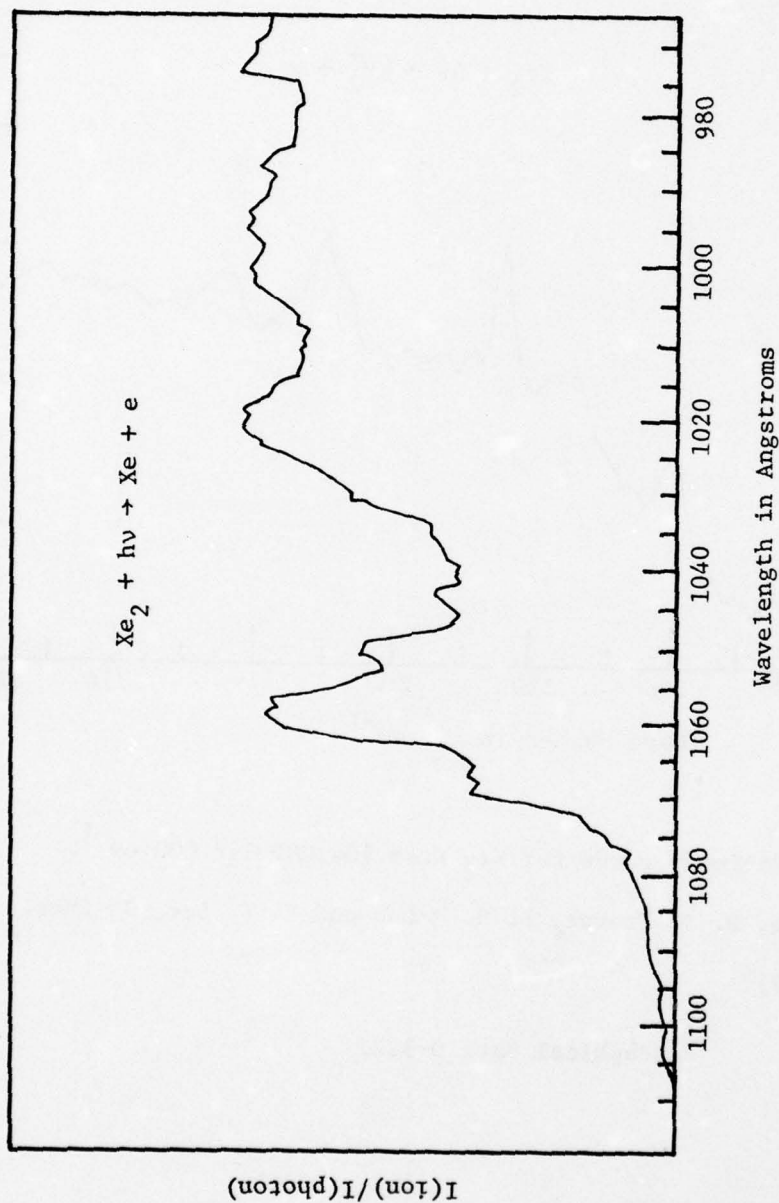
Graphical Data D-3.1.



Photoionization efficiency curve for Kr_2 from 104,000–118,000 cm^{-1} .

Taken from C. Y. Ng, D. J. Trevor, B. H. Mahan and Y. T. Lee, J. Chem. Phys. 66, 446 (1977).

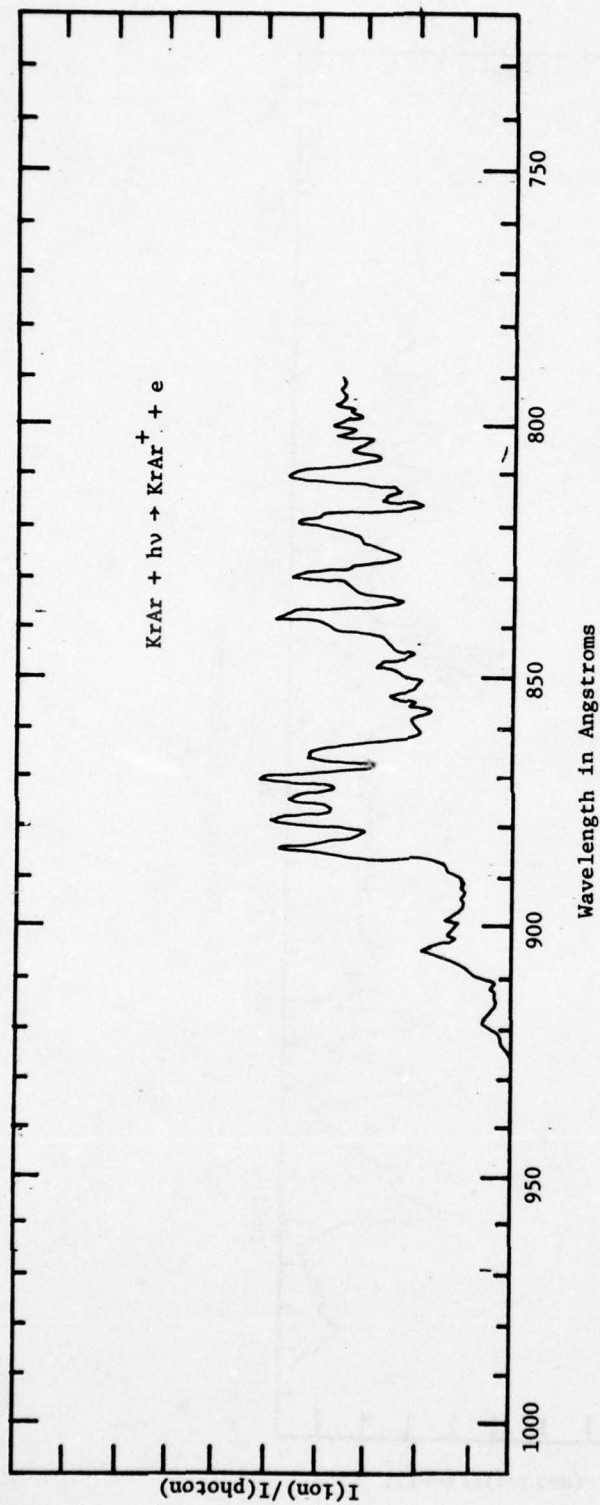
Graphical Data D-3.2.



Photoionization efficiency curve for Xe_2 from 965-1110 Å. Taken from C. Y. Ng, D. J. Trevor, B. H. Mahan and Y. T. Lee, J. Chem. Phys. 65, 4327 (1976).

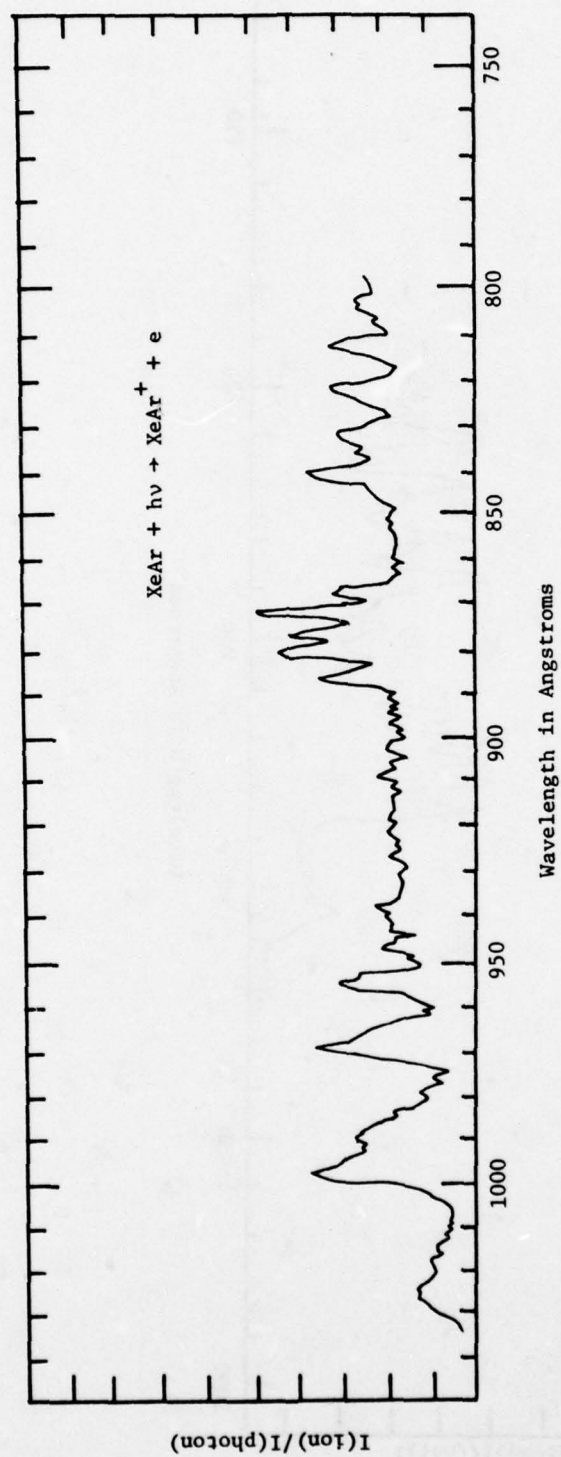
Graphical Data D-3.3.

Photoionization efficiency curve for KrAr from 790-930 Å. Taken from C.Y. Ng, P.W. Tiedemann, B.H. Mahan and Y.T. Lee, J. Chem. Phys. 66, 5737 (1977).

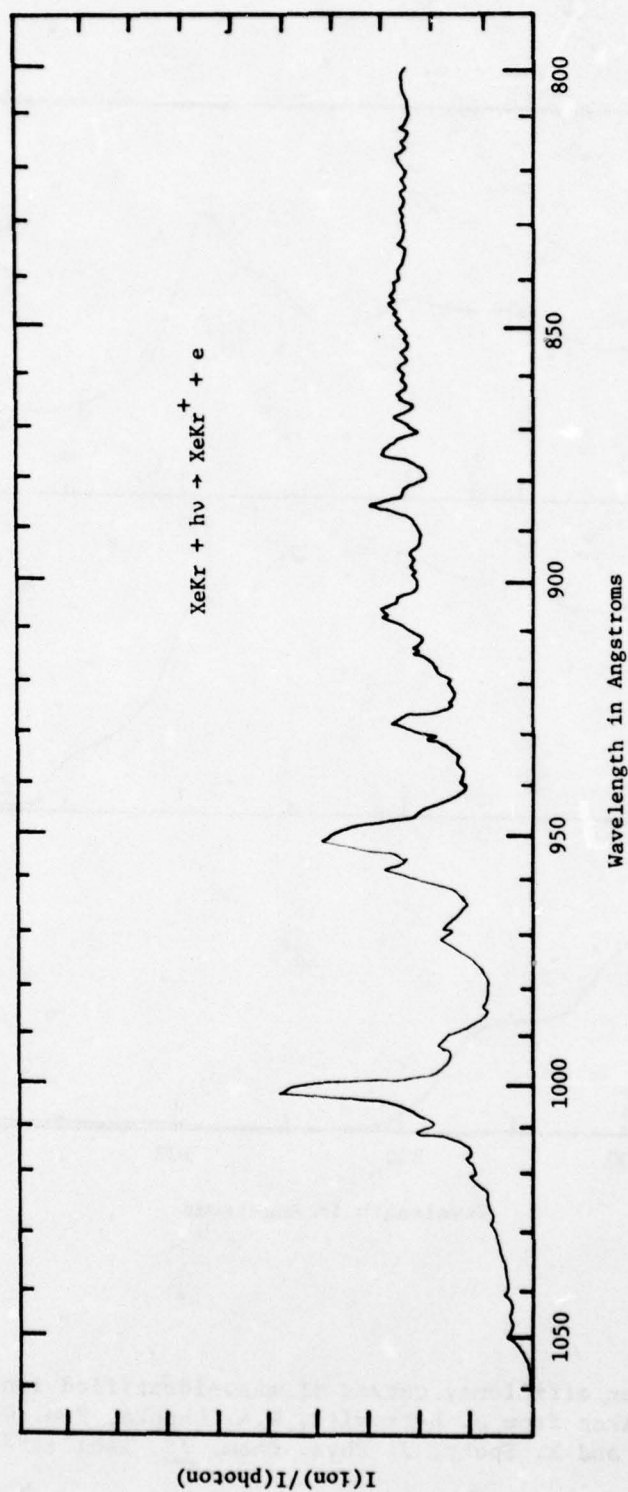


Graphical Data D-3.4.

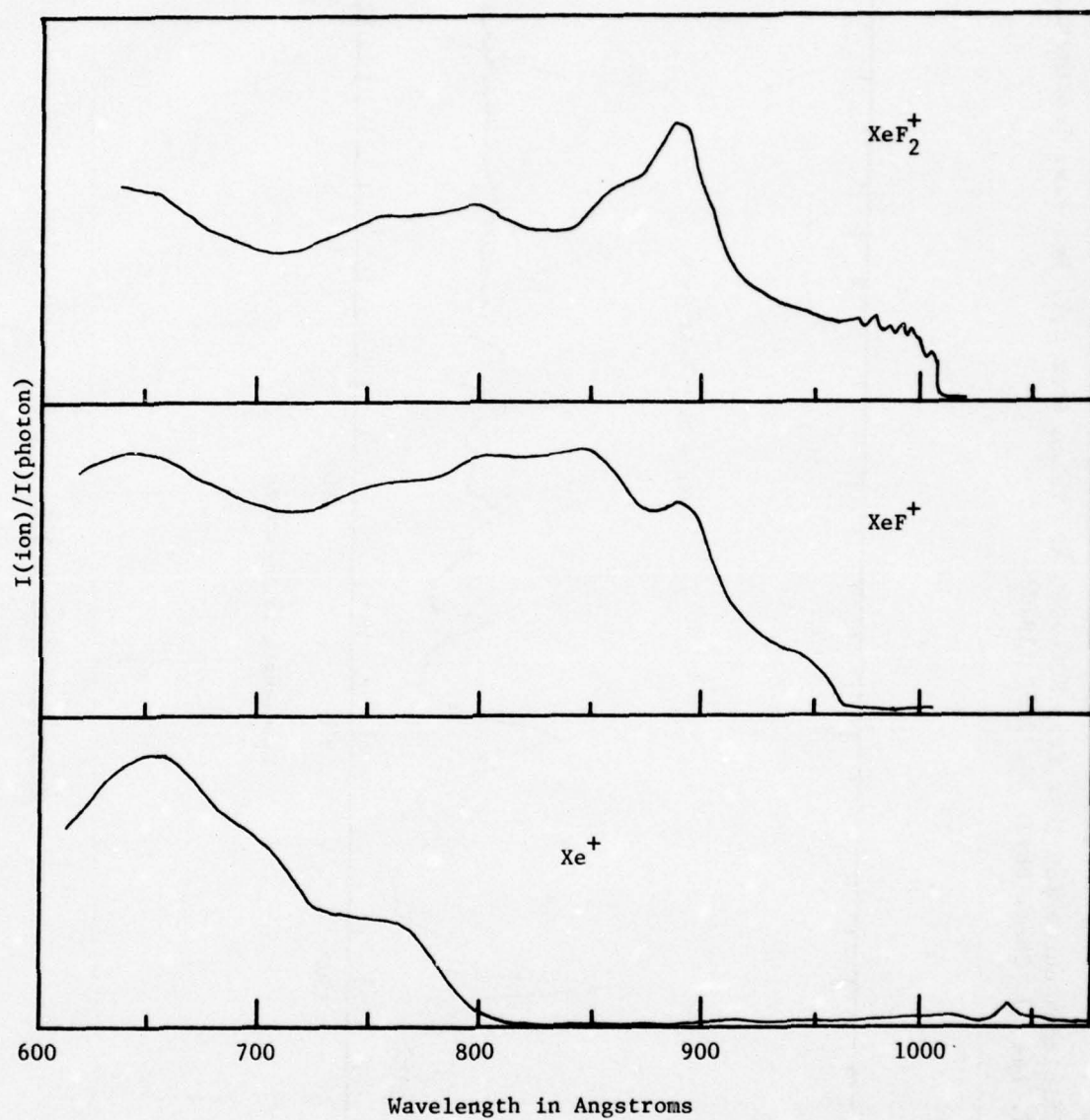
Photoionization efficiency curve for XeAr from 800-1040 Å. Taken from C.Y. Ng, P.W. Tiedemann, B.H. Mahan and Y.T. Lee, J. Chem. Phys. 66, 5737 (1977).



Photoionization efficiency curve for XeKr from 800-1060 Å. Taken from C.Y. Ng, P.W. Tiedemann, B.H. Mahan and Y.T. Lee, J. Chem. Phys. 66, 5737 (1977).

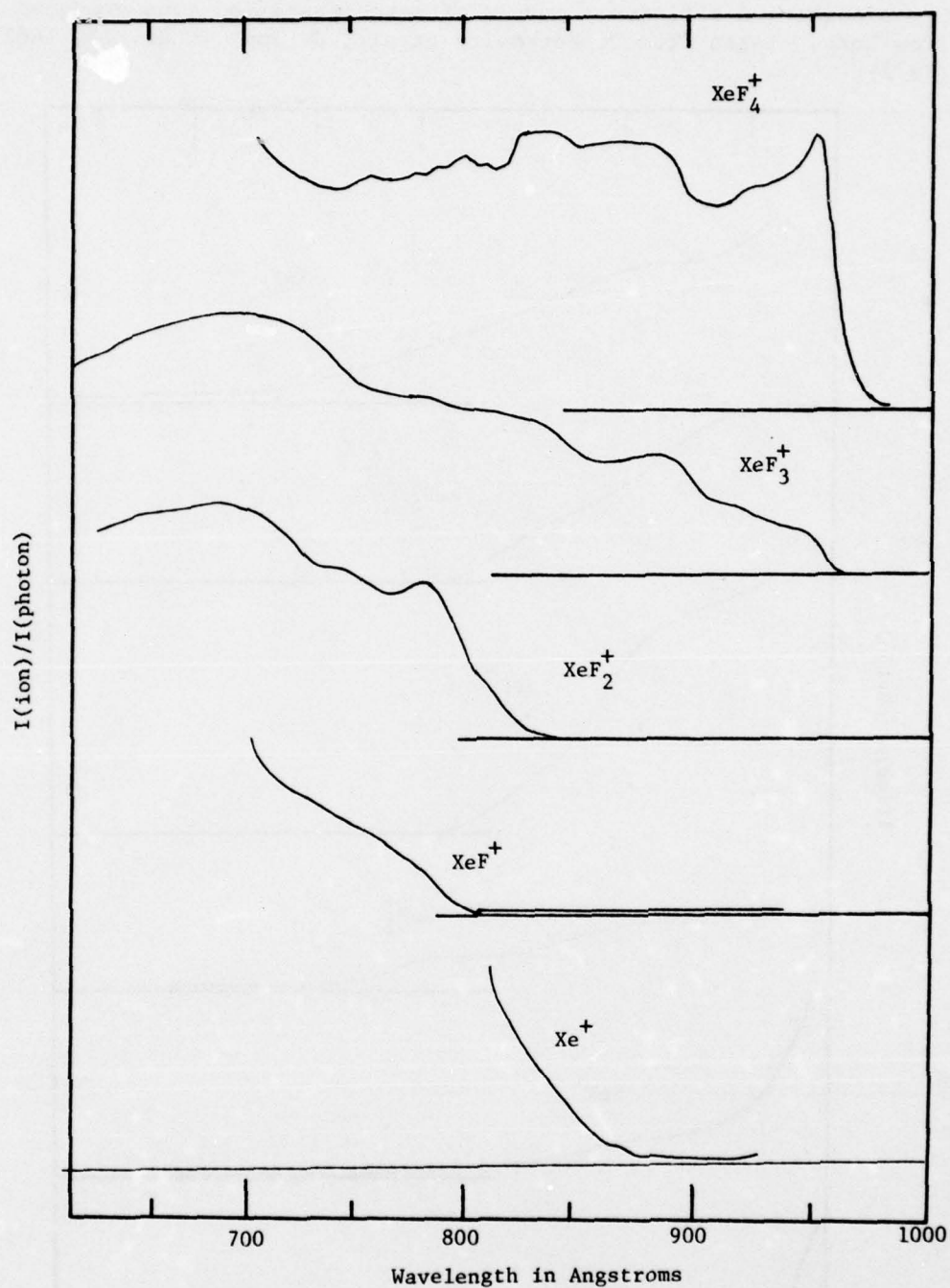


Graphical Data D-3.6.



Photoionization efficiency curves of mass-identified ions produced from XeF_2 . Taken from J. Berkowitz, W.A. Chupka, P.M. Guyon, J.H. Holloway and R. Spohr, J. Phys. Chem. 75, 1461 (1971).

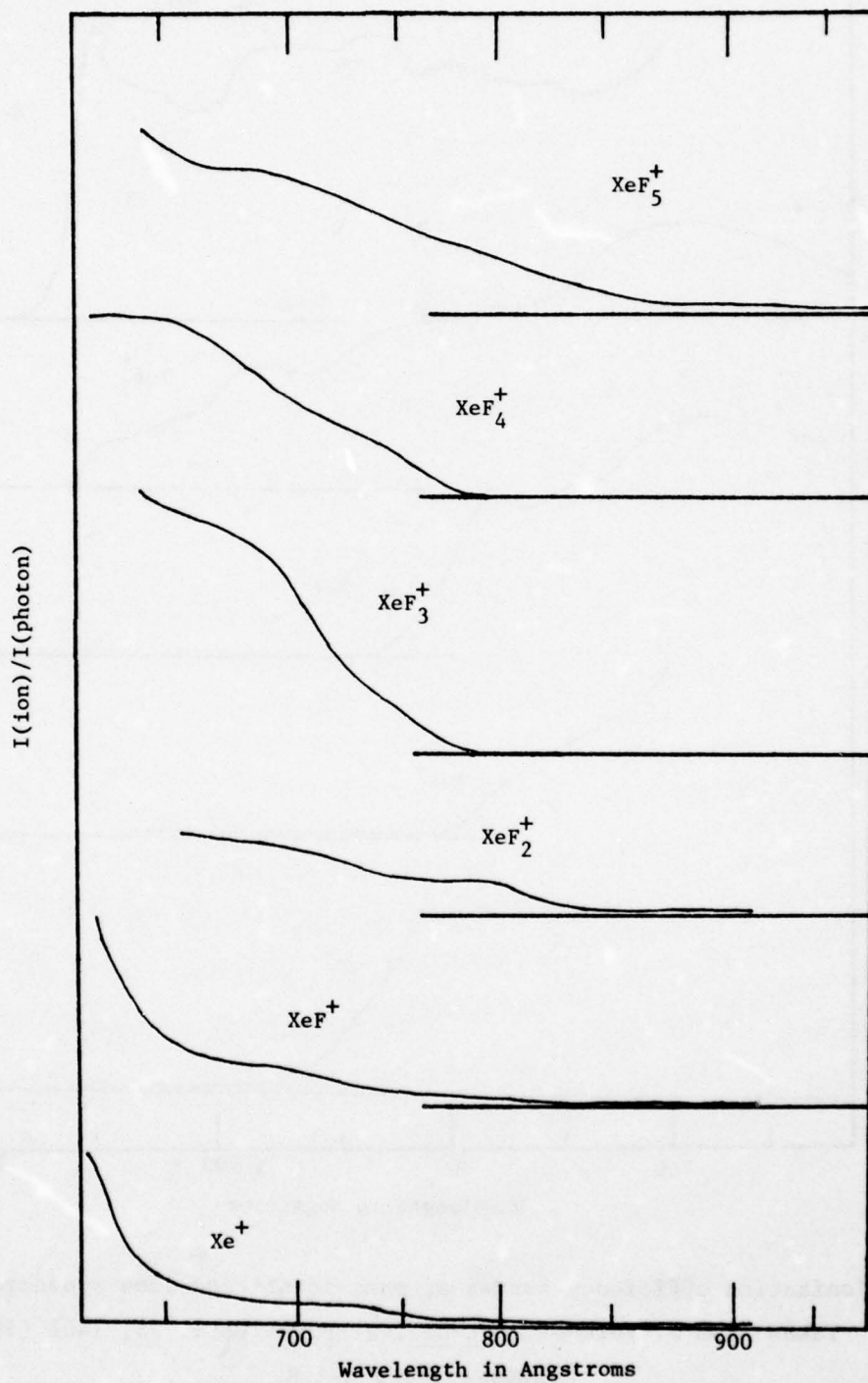
Graphical Data D-3.7.



Photoionization efficiency curves of mass-identified ions produced from XeF_4^+ . Taken from J. Berkowitz *et al.*, J. Phys. Chem. **75**, 1461 (1971).

Graphical Data D-3.8.

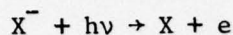
Photoionization efficiency curves of mass-identified ions produced from XeF_6 . Taken from J. Berkowitz et al., J. Phys. Chem. 75, 1461 (1971).



D-4. PHOTODETACHMENT CROSS SECTIONS
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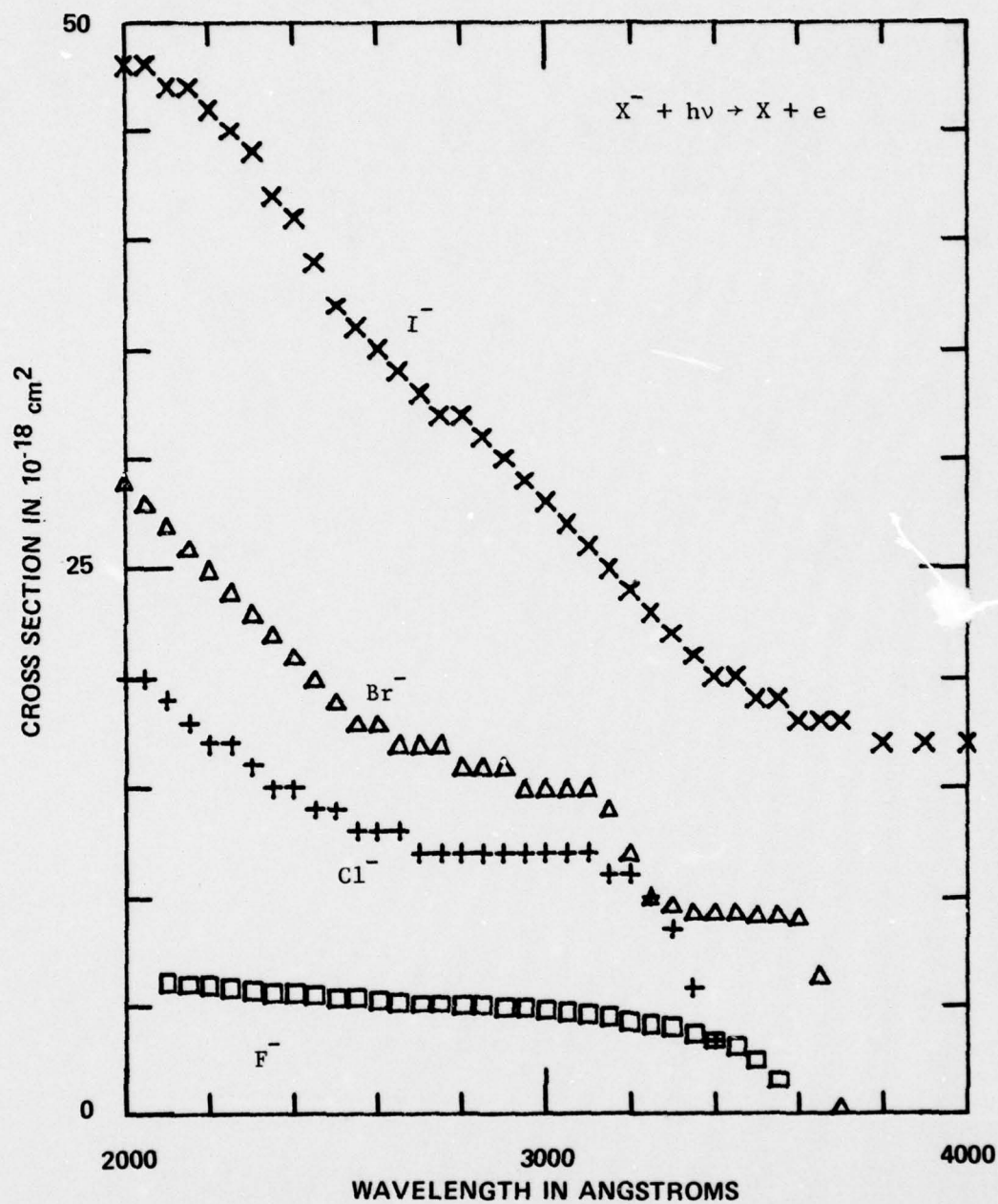
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Tabular Data D-4.1.
Electron Photodetachment Cross-Section σ for Halogen Atomic Ions



Wavelength in Angstroms, σ in 10^{-18} cm^2				
Wavelength	F ⁻	Cl ⁻	Br ⁻	I ⁻
1900				49
2000		20	29	48
2050		20	28	48
2100	6.1	19	27	47
2150	6.0	18	26	47
2200	5.9	17	25	46
2250	5.8	17	24	45
2300	5.7	16	23	44
2350	5.6	15	22	42
2400	5.6	15	21	41
2450	5.5	14	20	39
2500	5.4	14	19	37
2550	5.4	13	18	36
2600	5.3	13	18	35
2650	5.2	13	17	34
2700	5.1	12	17	33
2750	5.1	12	17	32
2800	5.0	12	16	32
2850	5.0	12	16	31
2900	4.9	12	16	30
2950	4.9	12	15	29
3000	4.8	12	15	28
3050	4.7	12	15	27
3100	4.6	12	15	26
3150	4.5	11	14	25
3200	4.3	11	12	24
3250	4.1	10	10	23
3300	4.0	8.5	9.6	22
3350	3.7	5.8	9.3	21
3400	3.4	3.4	9.3	20
3450	3.1		9.3	20
3500	2.5		9.2	19
3550	1.6		9.2	19
3600			9.1	18
3650			6.4	18
3700			0.4	18
3800				17
3900				17
4000				17
4100				17

The above data were taken from A. Mandl, Phys. Rev. A 3, 251 (1971); A Mandl, Phys. Rev. A 14, 345 (1976); and A. Mandl, private communication. The estimate by the author of the overall uncertainty in the absolute value of the measurements is $\pm 25\%$.



Electron photodetachment cross section for the halogen atomic ions. The data is taken from A. Mandl, Phys. Rev. A 3, 251 (1971), A. Mandl, Phys. Rev. A 14, 354 (1976); and A. Mandl, private communication. See Also H. Hotop and W.C. Lineberger, "Binding Energies in Atomic Negative Ions," J. Phys. Chem. Ref. Data 4, 539 (1975), and references therein.

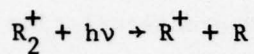
Graphical Data D-4.2.

D-5. PHOTODISSOCIATION CROSS SECTIONS
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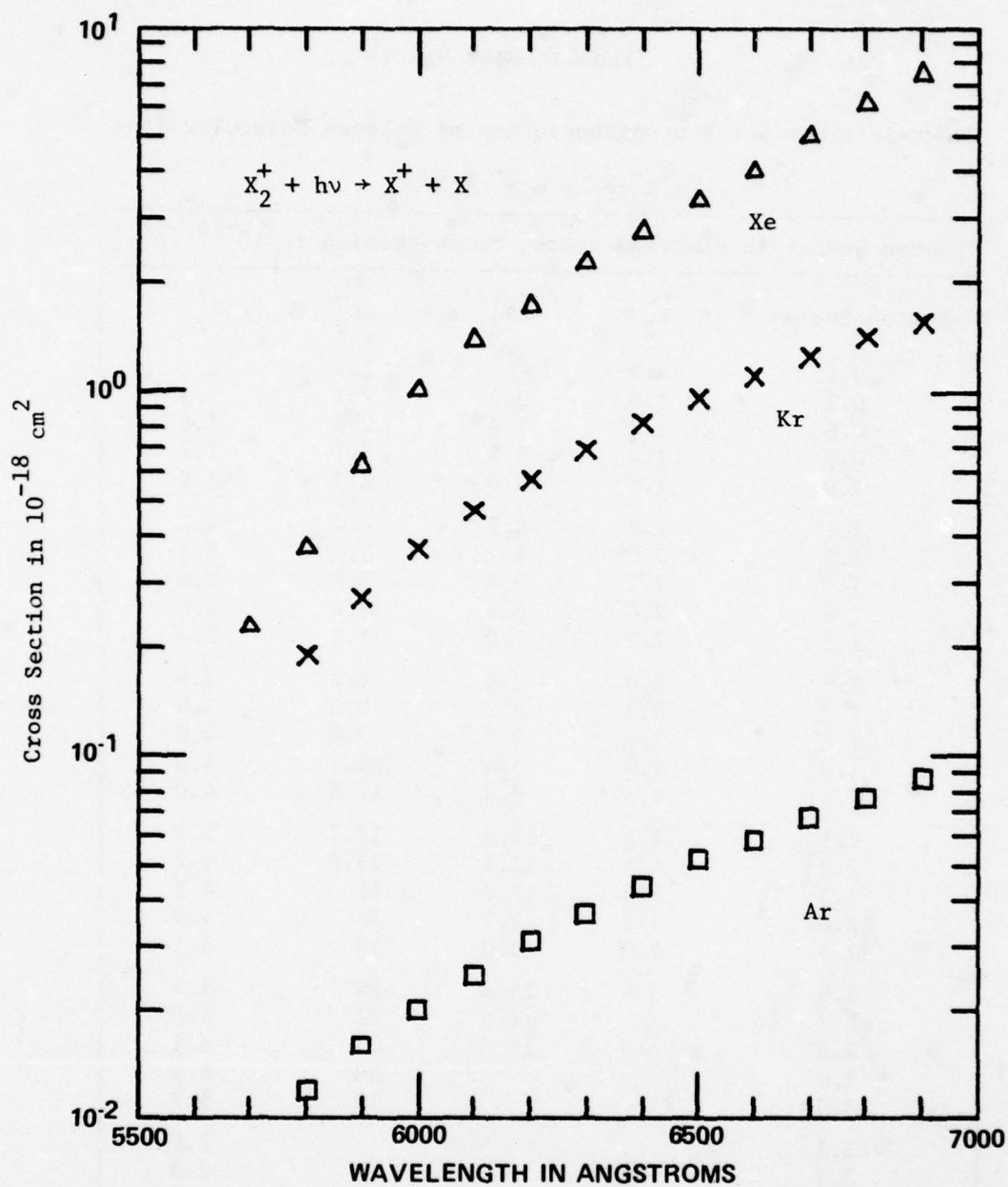
Tabular Data D-5.1.

Cross-Sections for Photodissociation of Rare Gas Dimer Ions



Wave length in Angstroms, Cross-Sections in 10^{-18} cm^2			
Wavelength	Ar_2^+	Kr_2^+	Xe_2^+
5700	0.008		0.23
5800	0.012	0.19	0.38
5900	0.016	0.27	0.64
6000	0.020	0.37	1.03
6100	0.025	0.47	1.41
6200	0.031	0.57	1.76
6300	0.037	0.69	2.3
6400	0.044	0.82	2.8
6500	0.052	0.95	3.4
6600	0.059	1.10	4.1
6700	0.068	1.24	5.1
6800	0.077	1.40	6.3
6900	0.087	1.55	7.6

The above data is taken from T. M. Miller, J. H. Ling, R. P. Saxon and J. T. Moseley, Phys. Rev. A 13, 2171 (1976). The estimate of the uncertainty in the absolute cross-sections is $\pm 25\%$. The authors also report an upper limit of $7 \times 10^{-21} \text{ cm}^2$ for the photodissociation cross-sections of He_2^+ and Ne_2^+ over the range of wavelengths above.

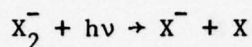


Cross section for the photodissociation of rare gas dimer ions from 5500-7000 Å. The data are taken from T.M. Miller, J.H. Ling, R.P. Saxon and J.T. Moseley, Phys. Rev. A 13, 2171 (1976).

Graphical Data D-5.2.

Tabular Data D-5.3.

Cross-Sections for Photodissociation of Halogen Molecular Ions

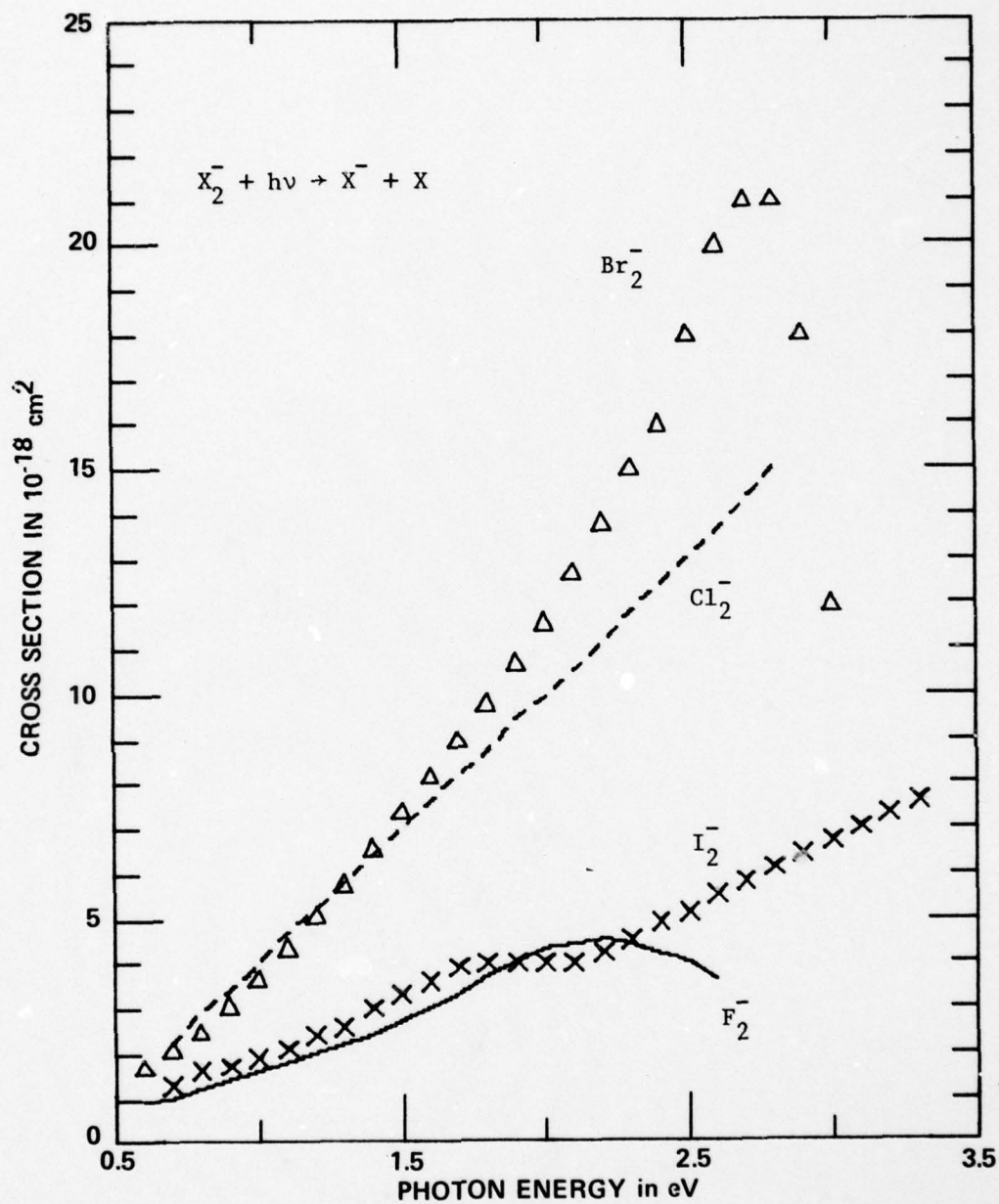


Photon Energy in electron volts, cross-section in 10^{-18} cm^2				
Photon Energy	F_2^-	Cl_2^-	Br_2^-	I_2^-
0.6	0.9		1.7	
0.7	1.0	2.2	2.1	1.3
0.8	1.2	2.9	2.5	1.6
0.9	1.4	3.4	3.1	1.7
1.0	1.6	4.0	3.7	1.9
1.1	1.8	4.7	4.4	2.1
1.2	2.0	5.2	5.1	2.4
1.3	2.2	5.8	5.8	2.6
1.4	2.4	6.4	6.6	3.0
1.5	2.7	7.0	7.4	3.3
1.6	3.0	7.6	8.2	3.6
1.7	3.3	8.2	9.0	3.9
1.8	3.7	8.7	9.8	4.0
1.9	4.0	9.4	10.7	4.0
2.0	4.3	9.9	11.6	4.0
2.1	4.4	10.5	12.7	4.0
2.2	4.5	11.1	13.8	4.2
2.3	4.4	11.8	15	4.5
2.4	4.2	12.4	16	4.9
2.5	4.0	13.0	18	5.1
2.6	3.6	13.6	20	5.5
2.7		14.3	21	5.8
2.8		15	21	6.1
2.9			18	6.4
3.0			12	6.7
3.1				7.0
3.2				7.3
3.3				7.6

The above data was taken from R. Rackwitz, D. Feldmann, E. Heinicke and H. J. Kaiser, Z. Naturforsch 29a, 1797 (1974).

The total uncertainty in the measurements is estimated by the authors to be $\pm 30\%$. The precision is quite a bit better than this.

See also H. Hotop and W. C. Lineberger, "Binding Energies in Atomic Negative Ions", J. Phys. Chem. Ref. Data 4, 539 (1975).



Cross sections for the photodissociation of halogen molecular ions. The data are taken from R. Rackwitz, D. Feldman, E. Heinicke, and H.J. Kaiser, Z. Naturforsch 29a, 1797 (1974).

Graphical Data D-5.4.

D-6. FREE-FREE ABSORPTION COEFFICIENTS

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Tabular Data D-6.1.

Continuous Free-Free Absorption Coefficients of Selected Atoms

Wavelength is in Angstroms. The absorption coefficient is in units per electron pressure per atom: $10^{-26} \text{ cm}^4/\text{dyne}$									
He + e ⁻ + hv → He + e ⁻									
λ (Å)	100°K	500°K	1000°K	2500°K	5000°K	7500°K	10000°K	12500°K	15000°K
5000	0.931	0.205	0.114	0.0579	0.0388	0.0319	0.0281	0.0263	0.0233
7500	1.72	0.389	0.224	0.122	0.0880	0.0740	0.0650	0.0596	0.0535
10000	2.67	0.620	0.366	0.214	0.159	0.134	0.118	0.107	0.0961
15000	4.98	1.21	0.756	0.484	0.370	0.310	0.269	0.243	0.218
Ne + e ⁻ + hv → Ne + e ⁻									
λ (Å)	100°K	500°K	1000°K	2500°K	5000°K	7500°K	10000°K	12500°K	15000°K
5000	0.0707	0.0220	0.0153	0.0105	0.0086	0.0078	0.0074	0.0071	0.0074
7500	0.132	0.0427	0.0307	0.0228	0.0198	0.0183	0.0172	0.0164	0.0164
10000	0.205	0.0691	0.0514	0.0405	0.0363	0.0335	0.0313	0.0296	0.0292
15000	0.386	0.139	0.109	0.0941	0.0854	0.0778	0.0719	0.0676	0.0659
Ar + e ⁻ + hv → Ar + e ⁻									
λ (Å)	100°K	500°K	1000°K	2500°K	5000°K	7500°K	10000°K	12500°K	15000°K
5000	1.09	0.0885	0.0243	0.0094	0.0096	0.0120	0.0147	0.0171	0.0189
7500	2.00	0.164	0.0450	0.0184	0.0211	0.0273	0.0337	0.0392	0.0436
10000	3.09	0.254	0.0703	0.0304	0.0374	0.0491	0.0606	0.0704	0.0782
15000	5.71	0.472	0.133	0.0641	0.0850	0.112	0.138	0.159	0.177
Kr + e ⁻ + hv → Kr + e ⁻									
λ (Å)	100°K	500°K	1000°K	2500°K	5000°K	7500°K	10000°K	12500°K	15000°K
5000	4.36	0.465	0.153	0.320	0.0162	0.0168	0.0194	0.0223	0.0225
7500	8.04	0.863	0.284	0.0592	0.0315	0.0356	0.0431	0.0507	0.0580
10000	12.4	1.34	0.443	0.0928	0.0512	0.0610	0.0757	0.0902	0.104
15000	22.9	2.52	0.843	0.178	0.104	0.131	0.168	0.203	0.236

(continued next page)

Tabular Data D-6.1. (Concluded)

Continuous Free-Free Absorption Coefficients of Selected Atoms

Wavelength is in Angstroms. The absorption coefficient is in units per electron pressure per atom: $10^{-26} \text{ cm}^4/\text{dyne}$									
$\text{Xe} + e^- + h\nu \rightarrow \text{Xe} + e^-$									
λ (Å)	100°K	500°K	1000°K	2500°K	5000°K	7500°K	10000°K	12500°K	15000°K
5000	20.2	1.80	0.558	0.113	0.0531	0.0529	0.0586	0.0651	0.0681
7500	37.2	3.34	1.04	0.211	0.108	0.117	0.134	0.150	0.160
10000	57.4	5.18	1.62	0.332	0.179	0.204	0.240	0.269	0.286
15000	106.0	9.71	3.07	0.639	0.369	0.447	0.541	0.611	0.644
$\text{Cl} + e^- + h\nu \rightarrow \text{Cl} + e^-$									
λ (Å)	1750°K	2000°K	2500°K	3000°K	4000°K	5000°K	7500°K	10000°K	12500°K
3500	2.64	2.08	1.43	1.03	0.650	0.462	0.248	0.164	0.120
4000	2.79	2.24	1.54	1.13	0.709	0.509	0.278	0.190	0.147
5000	3.17	2.56	1.79	1.35	0.868	0.628	0.361	0.257	0.203
6000	3.57	2.90	2.08	1.56	1.04	0.766	0.467	0.341	0.277
8000	4.57	3.76	2.76	2.14	1.48	1.12	0.735	0.562	0.466
10000	5.90	4.92	3.66	2.90	2.06	1.61	1.08	0.841	0.657

The above are results of theoretical calculations reported by T.L. John, Mon. Not. R. Astr. Soc. 172, 305 (1975) and T.L. John and D.J. Morgan, Mon. Not. R. Astr. Soc. 170, 1 (1975). The values for Cl result from interpolation of the reported values. For the rare gas atoms, the author estimates that the results may be low by 10-15% at 10000 angstroms, and by 30-40% at 5000 angstroms. At higher wavelengths the accuracy is estimated to be a few per cent.

D-7. REFRACTIVE INDICES
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D-7.2 Refractive Indices of the Halogens in the Visible . .	697

Tabular Data D-7.1.

Refractive Indices for the Rare Gases

Wavelength in Angstroms, refractive index is given as $(n-1) \times 10^{-6}$					
Wavelength	He	Ne	Ar	Kr	Xe
1700	37.73			578	
1800	37.32			551	
1900	36.98			533	
2000	36.72			517	
2100	36.50			506	
2200	36.33			497	872
2300	36.20		309.3	488	852
2400	36.08		306.2	481	834
2500	35.97		303.7	476	820
2600	35.86		301.6	471	808
2700	35.77		299.7	467	798
2800	35.68		297.9	463	788
2900	35.61	68.58	296.4	460	778
3000	35.54	68.46	294.9	457	771
3200	35.42	68.26	292.5	452	758
3400	35.33	68.08	290.6	448	748
3600	35.25	67.92	289.2	444	740
3800	35.18	67.79	288.1	442	734
4000	35.12	67.67	287.1	440	728
4200	35.08	67.58	286.2	438	724
4400	35.04	67.51	285.4	437	720
4600	35.01	67.44	284.7	435	717
4800	34.98	67.38	284.0	434	714
5000	34.95	67.33	283.4	433	711
5500	34.89	67.24	282.3	431	706
6000	34.85	67.16	281.6	429	702
6500	34.82	67.10	281.1	428	699
7000	34.79		280.6		
8000	34.75		279.8		
9000	34.72		279.3		
10000	34.70		278.9		

The above data is interpolated from measurements reported by P. J. Leonard, Atomic Data and Nuclear Data Tables 14, 21 (1974), and by P. L. Smith, M. C. E. Huber and W. H. Parkinson, Phys. Rev. A 13, 1422 (1976).

Tabular Data D-7.2.

Refractive Indices for Molecular Halogen Gases

Wavelengths are in Angstroms. The refractive index is given as $(n-1) \times 10^{-6}$

F ₂		Cl ₂	
λ	$(n-1) \times 10^6$	λ	$(n-1) \times 10^6$
5893	195.	4800	791.7
		5086	787.9
		5209	786.5
		5461	784.0
		5770	781.4
		5791	781.2
		6439	777.0
		6708	775.6
Br ₂		I ₂	
λ	$(n-1) \times 10^6$	λ	$(n-1) \times 10^6$
5461	1185	5000	2120
5600	1180	5005	2160
5700	1176	5100	2210
5750	1174	5250	2250
5800	1174	5600	2170
6000	1166	6180	2130
6438	1157	6215	2130
6708	1153	6438	2110
		6708	1970

The above data were taken from the International Critical Tables, E.W. Washburn (Ed.), McGraw-Hill, New York, 1930, Vol VII. The values for F₂ and for I₂ must be considered only approximate.

D-8. MULTIPHOTON IONIZATION
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D-8.1 (a) Multiphoton Parameter for H ₂ , He, Ne, Ar, Kr, and Xe	
(b) Radiation Intensity Required for Ionization Rate of $10^{7\pm1} \text{ sec}^{-1}$	700

Tabular Data D-8.1.
Multiphoton Ionization of Gases

Notation: $N = AK^k$, WHERE

N is the total number of ions produced, A is a constant for a given photon energy and density, gas species and density and duration of radiation pulse, and K is the number of photons required to exceed the ionization potential.

(a) Value of Exponential Multiphoton Parameter K						
Gas	$\lambda = 10600 \text{ \AA}$		$\lambda = 6900 \text{ \AA}$		$\lambda = 5300 \text{ \AA}$	
	Exp.	Theory	Exp.	Theory	Exp.	Theory
H ₂	8 ± 1	14				
He	18 ± 0.3	21	14	14	9.2 ± 0.3	11
Ne	13.7 ± 0.3	19			7.3 ± 0.3	10
Ar	10.3 ± 0.3	14	9	9	5.7 ± 0.3	7
Kr	9 ± 0.3	12	6.31	8	5.5 ± 0.3	6
Xe	8.7 ± 0.3	11	6.23	7	4.1 ± 0.3	6

(b) Radiation Intensity (in Watts/cm ²) Required to Produce an Ionization Rate of 10^{7+1} Ions/Sec		
Gas	$\lambda = 10600 \text{ \AA}$	$\lambda = 5300 \text{ \AA}$
He	2.6×10^{13}	3.6×10^{12}
Ne	2.2×10^{13}	3.2×10^{12}
Ar	0.66×10^{13}	0.35×10^{12}
Kr	0.32×10^{13}	0.22×10^{12}
Xe	0.24×10^{13}	0.14×10^{12}

These data are taken from the excellent review articles: D. C. Smith and R. G. Meyerand Jr., "Laser Radiation Induced Gas Breakdown", in G. Bekefi (Ed.) Principles of Laser Plasmas, (Wiley) 1976, and P. Lambropoulos, "Topics on Multiphoton Processes in Atoms", in D. R. Bates and B. Bederson (Eds.) Advances in Atomic and Molecular Physics, Vol. 12, (Academic) 1976. Most experimental data came from P. Agostini et al., IEEE J. Quantum Electron. 12, 782 (1970), referred to by both review articles.

D-9. EXTINCTION COEFFICIENTS

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Tabular Data D-9.1.
Extinction Coefficient ϵ for Continuous Absorption of the Halogen
and Mixed Halogen Molecules at $T = 298 \pm 3^\circ\text{K}$

$I = I_0 10^{-\epsilon cx}$; c in moles/liter, x in cm., and ϵ in liters/mole-cm							
Wavelength (\AA)	F_2	Cl_2	Br_2	I_2	BrCl	ICl	IBr
2100	1.10						
2200	1.60				17.5	55.8	9.4
2300	2.18				18.8	92.5	14.9
2400	3.02	0.2			16.3	115.1	26.7
2500	3.98	0.3			11.5	113.3	43.7
2600	4.94	0.6			7.7	92.2	56.1
2700	5.63	2.3			4.2	63.7	60.4
2800	5.95	7.0			2.5	40.3	55.2
2900	5.95	17.0			1.4	24.6	44.0
3000	5.59	31.4			1.3	15.9	32.5
3100	4.94	48.3			3.9	12.0	20.8
3200	4.14	61.8	0.2		10.0	10.5	14.1
3300	3.35	67.0	0.8		23.6	9.6	8.8
3400	2.56	61.8	2.9		45.4	8.6	5.6
3500	1.89	49.6	10.0		71.4	8.1	3.8
3600	1.35	34.4	23.3		94.9	9.2	4.0
3700	0.92	21.8	47.6		107.4	13.9	6.2
3800	0.63	12.9	81.4		106.3	23.0	10.9
3900	0.41	8.6	119.0		93.7	36.3	18.2
4000	0.30	5.0	148.9		76.6	49.6	31.5
4100	0.21	3.5	165.0		60.0	64.5	53.5
4200	0.14	2.6	165.5	12.5	47.9	75.5	83.0
4300	0.10	1.9	155.5	22.2	39.6	83.9	117.1
4400	0.07	1.4	140.8	43.7	34.3	92.7	153.5
4500	0.06	0.9	127.4	79.	30.2	101.6	188.1
4600			117.1	138.	26.8	109.0	222.8
4700			108.4	221.	23.0	111.4	257.6
4800			101.5	326.	18.6	107.0	290.6
4900			93.2	454.	14.2	95.0	313.5
5000			82.9	574.	10.5	77.0	318.2
5100			70.7	710.	7.4	59.6	303.2
5200			46.2	753.		42.9	269.6
5300			33.5	810.		30.0	224.5
5400			26.3	720.		20.9	176.6
5500			20.7	600.		14.9	136.9
5600			16.1	505.		11.3	95.8
5700			11.9	341.		9.0	71
5800			8.8	224.		7.4	52.0
5900			6.1	174.		5.5	38.1
6000				155.		4.6	29.6

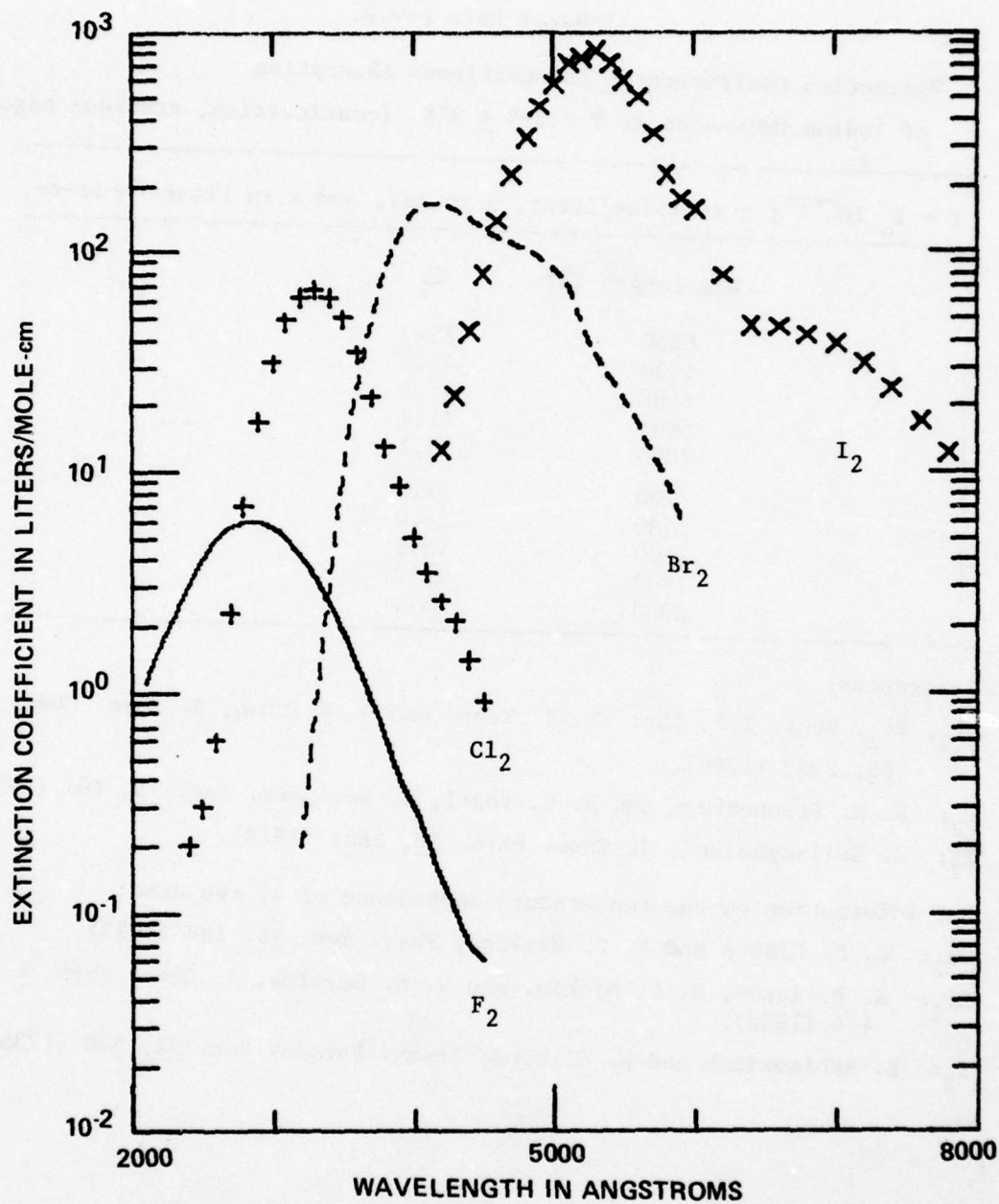
Tabular Data D-9.2.

Extinction Coefficient ϵ for Continuous Absorption
of Iodine Molecules at $T = 298 \pm 3^\circ\text{K}$ (continuation, previous page)

$I = I_0 10^{-\epsilon c x}$; c in moles/liter, x in cm., and ϵ in liters/mole-cm	
Wavelength (\AA)	I_2
6200	78.
6400	45.8
6600	45.2
6800	41.7
7000	38.1
7200	31.0
7400	24.0
7600	16.9
7800	12.2
8000	8.4

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- Cl_2 , Br_2 , BrCl , ICl , IBr : D. J. Seery and D. Britton, J. Phys. Chem. 68, 2263 (1964).
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- I_2 : J. Tellinghuisen, J. Chem. Phys. 58, 2821 (1973).
- For information on the temperature dependence of ϵ , see also:
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Extinction coefficient for the gases F_2 , Cl_2 , Br_2 and I_2 . The values are taken from the preceding table, and are for $T = 298^\circ K$.

Graphical Data D-9.3.

D-10. UV EMISSION AND ABSORPTION SPECTRA

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UV Emission and Absorption Spectra

In this section we attempt to summarize spectroscopic observations on rare gas, halogen and rare gas- halide species. There are a variety of fundamental processes which result in emission or absorption of photons. Where cross sections are available for specific fundamental processes (i.e. photoionization, photodetachment), they are included elsewhere in Part D. Often, however, observation of emission and/or absorption spectra (line, band and continuum) are reported for which only the wavelength range and (perhaps) relative intensities are measured. Assignment of spectral phenomena to specific atomic or molecular transitions is frequently made. In many cases the observed spectra depend strongly on such experimental parameters as gas temperature, gas pressure, and (in emission) method of excitation (particle impact, quiet or interrupted discharge, flame, etc.).

We shall not attempt to list the hundreds of observed spectral lines and bands, or to give relative intensities or location of structure in such spectra. We will instead present a bibliography where such information may be found. Where compilations of data exist these are given preference, since they contain further references to the original work. Where there are a large number of articles, preference is given to the more recent papers, and to those containing the most complete lists of references to previous work.

Atomic Spectra:

1. C. E. Moore, Atomic Energy Levels, in 3 volumes, Publication No. 35 of the National Standard Reference Data System of the National Bureau of Standards (1972). No intensity information is given.
2. W. F. Meggars, C. H. Corliss and B. Scribner, Tables of Spectral-Line Intensities, National Bureau of Standards Monograph No. 145 (1975). See the review in J. Opt. Soc. Am. 65, 1528 (1975).

Molecular Spectra:

- A. Rare Gases: For photon energies above the photoionization threshold absorption in the noble gases is virtually identical to the photoionization cross section (treated elsewhere). For wavelengths longer than the photoionization threshold both band and continuous spectra have been reported, presumably due to the presence of rare gas dimer species. Continuous emission from rare gases have been observed for some time. References 1-4 report various continua and conditions under which they have been observed. The figure on page 711, taken from Ref. 2, gives the overall wavelength range for emission from rare gases, though not all this range is observed in each type of excitation or at a given gas pressure. More recent observations are reported in Ref. 5 (argon and krypton), Ref. 6 (xenon), Ref. 7 (krypton and argon/xenon mixtures) and Ref. 8 (krypton).

For a detailed examination of the UV absorption band spectra of rare gas diatomic molecules, the series of papers from the U. S. Air Force Cambridge Research Laboratories (Refs. 9-13) treat, respectively, He_2 , Ne_2 , Ar_2 , Kr_2 , and Xe_2 . Some information is included on HeNe (Ref. 10) and ArKr (Ref. 12). A comprehensive treatment of all the heteronuclear rare gas dimers is given in Ref. 14. Other recent papers of interest are Ref. 15 (Ar_2) and 16 (Xe_2).

- B. Halogen Gases: The homonuclear halogen molecules F_2 , Cl_2 , Br_2 and I_2 have been studied spectroscopically for many years, and data is included in several compilations (see tabulation of extinction coefficients elsewhere in Part D). One of the most extensive and complete of these is Ref. 17. In addition to the homogeneous diatomic neutral halogen molecules, the species Cl_2^+ , Br_2^+ , ClF , BrF , BrCl , IF , ICl , and IBr are included. Information is given (usually) on source condition, band head location and degrading direction, and transition assignment. Although information on some species (eg. BrCl) is sketchy, the authors include their own estimates of relative intensities whenever possible, often taken from published photographs. A more recent, though less complete data compilation is Ref. 18, published

D-10.2. (Concluded)

in two Volumes: Volume 1 (in two books; Parts A and B) is devoted to heterogeneous diatomic molecules. None of the rare gas dimers is included. The mixed halogens ClF, BrCl, IBr, and ICl are treated, though no intensity information is given for ClF or BrCl. There is a quite good bibliography for each species, including references later than 1963, the publication date of Ref. 17. We were not able to obtain Volume 2, which is devoted to homogeneous diatomic molecules, but presumably F_2 , Cl_2 , Br_2 and I_2 are included.

- C. Rare Gas-Halogen Mixtures: There are many recent articles, many specifically related to lasers and stimulated emission. We list some of these as References 19 through 28, including titles. A theoretical interpretation of rare gas-halide spectra is given in Ref. 29.

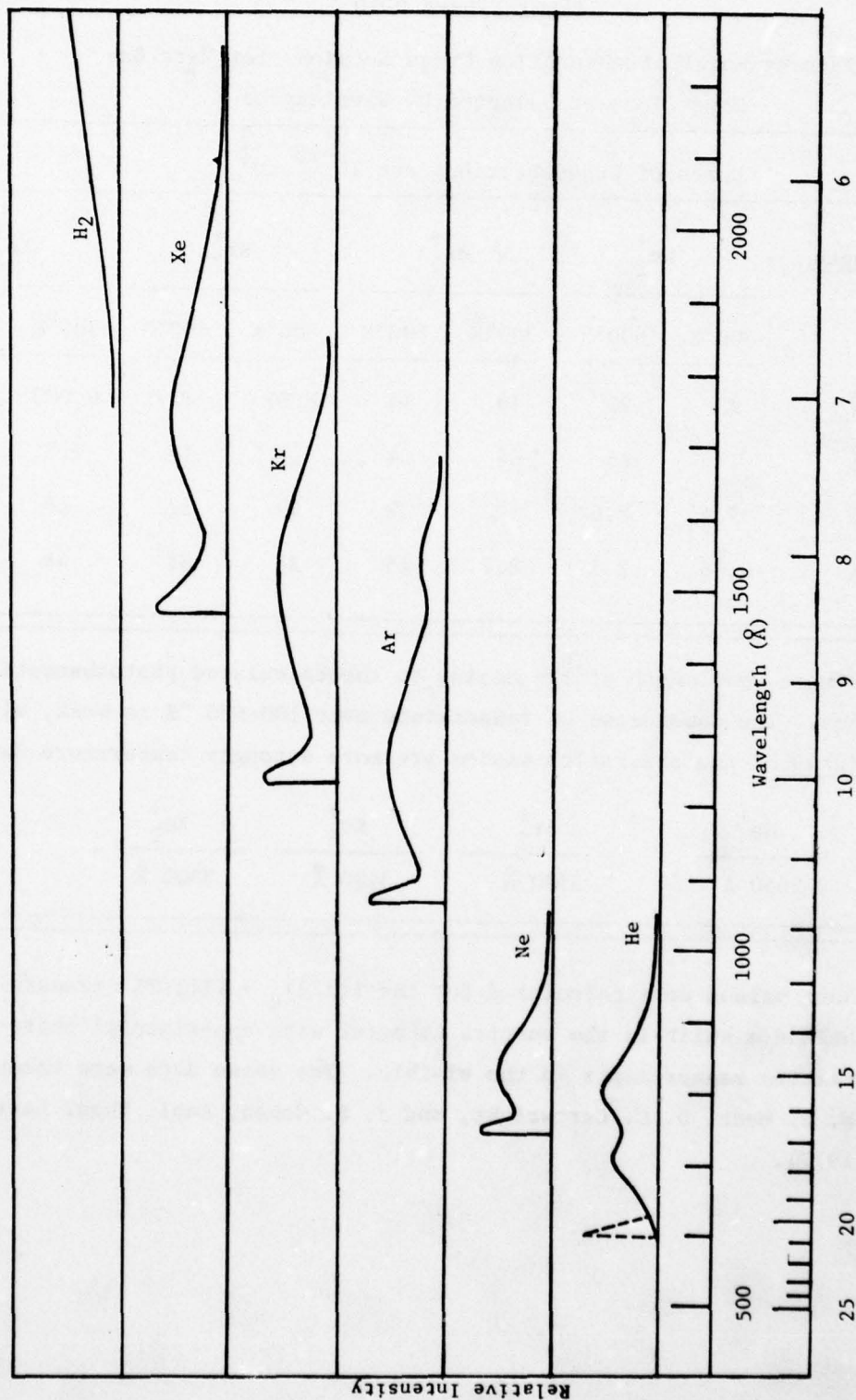
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Graphical Data D-10.4.

Tabular Data D-10.5.

Theoretical Photoabsorption Cross Sections for Rare Gas
Dimer Ions at Selected UV Wavelengths

Units of Cross Sections are 10^{-18} cm^2								
Wavelength	Ne_2^+		Ar_2^+		Kr_2^+		Xe_2^+	
	300°K	600°K	300°K	600°K	300°K	600°K	300°K	600°K
2480 Å	23	21	10	14	0.31	1.7	0.003	0.041
2820 Å	17	15	44	34	14	19	1.7	5.9
3080 Å	7.4	8.6	39	32	40	32	16	18
3520 Å	0.96	2.5	8.7	15	36	31	48	34

Approximate wavelength of the maxima in the calculated photoabsorption cross sections. The dependence on temperature over 100-600 °K is weak, although the widths of the absorption maxima are more strongly temperature dependent.

Ne_2^+	Ar_2^+	Kr_2^+	Xe_2^+
2650 Å	3300 Å	3400 Å	3800 Å

The above values were calculated for the $\text{I}(1/2)_u \rightarrow \text{II}(1/2)_g$ transitions, and include a shift in the spectra to agree with experimental photodissociation measurements in the visible. The above data were taken from W. R. Wadt, D. C. Cartwright, and J. S. Cohen, Appl. Phys. Lett. 31, 672 (1977).

Tabular Data D-10.6.

Photoabsorption Cross Sections for Excited Rare Gas Dimers at
Selected UV Wavelengths

Xe_2^*	$\frac{2530 \text{ \AA}}{8 \times 10^{-18} \text{ cm}^2}$	$\frac{2820 \text{ \AA}}{1.1 \times 10^{-17} \text{ cm}^2}$	$\frac{3080 \text{ \AA}}{1.4 \times 10^{-17} \text{ cm}^2}$	
Kr_2^*	$\frac{1850 \text{ \AA}}{3 \times 10^{-18} \text{ cm}^2}$	$\frac{2060 \text{ \AA}}{4 \times 10^{-18} \text{ cm}^2}$	$\frac{2220 \text{ \AA}}{5 \times 10^{-18} \text{ cm}^2}$	$\frac{2490 \text{ \AA}}{3 \times 10^{-18} \text{ cm}^2}$
Ar_2^*	$\frac{1610 \text{ \AA}}{2 \times 10^{-18} \text{ cm}^2}$	$\frac{1750 \text{ \AA}}{3 \times 10^{-18} \text{ cm}^2}$	$\frac{1930 \text{ \AA}}{4 \times 10^{-18} \text{ cm}^2}$	
Ne_2^*	$\frac{1080 \text{ \AA}}{6 \times 10^{-19} \text{ cm}^2}$			

The above values were taken from C. A. Brau, "Rare Gas-Halide Lasers", in C. K. Rhodes (Ed.), Eximer Lasers, Springer-Verlag, Berlin, 1978. The numbers were evaluated from information appearing in the report "Eximer Formation and Decay Processes in Rare Gases", by D. C. Lorents, D. J. Ekstrom, and D. Huestis, (AD - 778 326) Stanford Research Institute Report MP 73-2 (September, 1973).

E. TRANSPORT PROPERTIES OF ELECTRONS, IONS, AND NEUTRALS IN GASES

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E-1. TRANSPORT PROPERTIES OF ELECTRONS

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Definitions and Relationships

\vec{v}_d = drift velocity of electron = average velocity of drift along field lines in a gas exposed to a constant, uniform electric field, \vec{E} . \vec{v}_d is usually expressed in cm/sec.

K = mobility of electron, defined by the equation $\vec{v}_d = K \vec{E}$. K is usually expressed in $\text{cm}^2/\text{V-sec}$.

E/N = electron energy parameter = ratio of electric field intensity to gas number density. E/N is usually expressed in units of $(\text{volts/cm}) / (1/\text{cm}^3) = \text{V-cm}^2$.

T_d = unit of E/N , the "Townsend" = 10^{-17} V-cm^2 .

\leftrightarrow
 D = $\begin{vmatrix} D_T & 0 & 0 \\ 0 & D_T & 0 \\ 0 & 0 & D_L \end{vmatrix}$ = electron diffusion tensor.

D_L = (scalar) longitudinal diffusion coefficient = coefficient of diffusion along electric field.

D_T = (scalar) transverse diffusion coefficient = coefficient of diffusion transverse to electric field.

D_L/K and D_T/K are measures of the average electron energy at a given E/N .

In the limit $E/N \rightarrow 0$, $D_L = D_T = D$, the scalar diffusion coefficient.

For electrons in a given gas at a given temperature, the drift velocity, mobility, diffusion coefficients, and average energy are functions of E/N alone.

σ_m = electron momentum transfer cross section (considering only elastic impacts), defined by the equation

$$\sigma_m = \int (1 - \cos \theta) I_s(\theta) d\Omega_{CM}$$

where θ is the scattering angle in the center-of-mass system and $I_s(\theta)d\Omega_{CM}$ is the differential scattering cross section.

Before about 1970, the energy parameter was usually expressed in terms of E/p , where p is the gas pressure in units of mm Hg (i.e., Torr). To convert from E/p to E/N , one may use the relation

$$E/N \text{ (in } T_d) = (1.0354 \times T \times 10^{-2}) (E/p) \text{ where } T \text{ is the gas temperature.}$$

Tabular Data E-1.1

Experimentally determined transport coefficients for electrons in helium.

E/N (Td)	77K	293K			
	v_d (10^5 cm sec^{-1})	v_d (10^5 cm sec^{-1})	D_T/K (10^{-2} V)	ND_T ($10^{21} \text{ cm}^{-1} \text{ sec}^{-1}$)	D_L/K (10^{-2} V)
0.0				6.41	
1.0×10^{-2}	0.412			6.46	
3.0	0.845	0.631	3.36	7.03	2.71
5.0	1.124	0.922	4.20	7.78	2.97
7.0	1.343	1.156	5.09	8.38	3.47
1.0×10^{-1}	1.612	1.446	6.45	9.22	3.90
2.0	2.27	2.14	10.88	11.50	6.08
3.0	2.76	2.65	15.21	13.30	7.95
5.0	3.53	3.44	23.6	16.20	11.87
8.0	4.41	4.35	35.6	19.30	
1.0×10^0	4.91	4.85	43.4	20.9	
1.4	5.78	5.73	59.4	23.7	
1.7	6.36	6.33	70.9	25.7	
2.0		6.86	82.7	27.7	
2.5		7.68	102.5	30.8	
3.0		8.49	122.7	33.7	
3.5		9.26		36.6	
4.0		10.01		39.5	
5.0		11.52		45.5	
6.0		13.13		52.1	
7.0		15.03		59.3	
8.0				66.7	

Data taken from Chapter 14 of the book by Huxley and Crompton, and from H. B. Milloy and R. W. Crompton, Phys. Rev. A 15, 1847 (1977).

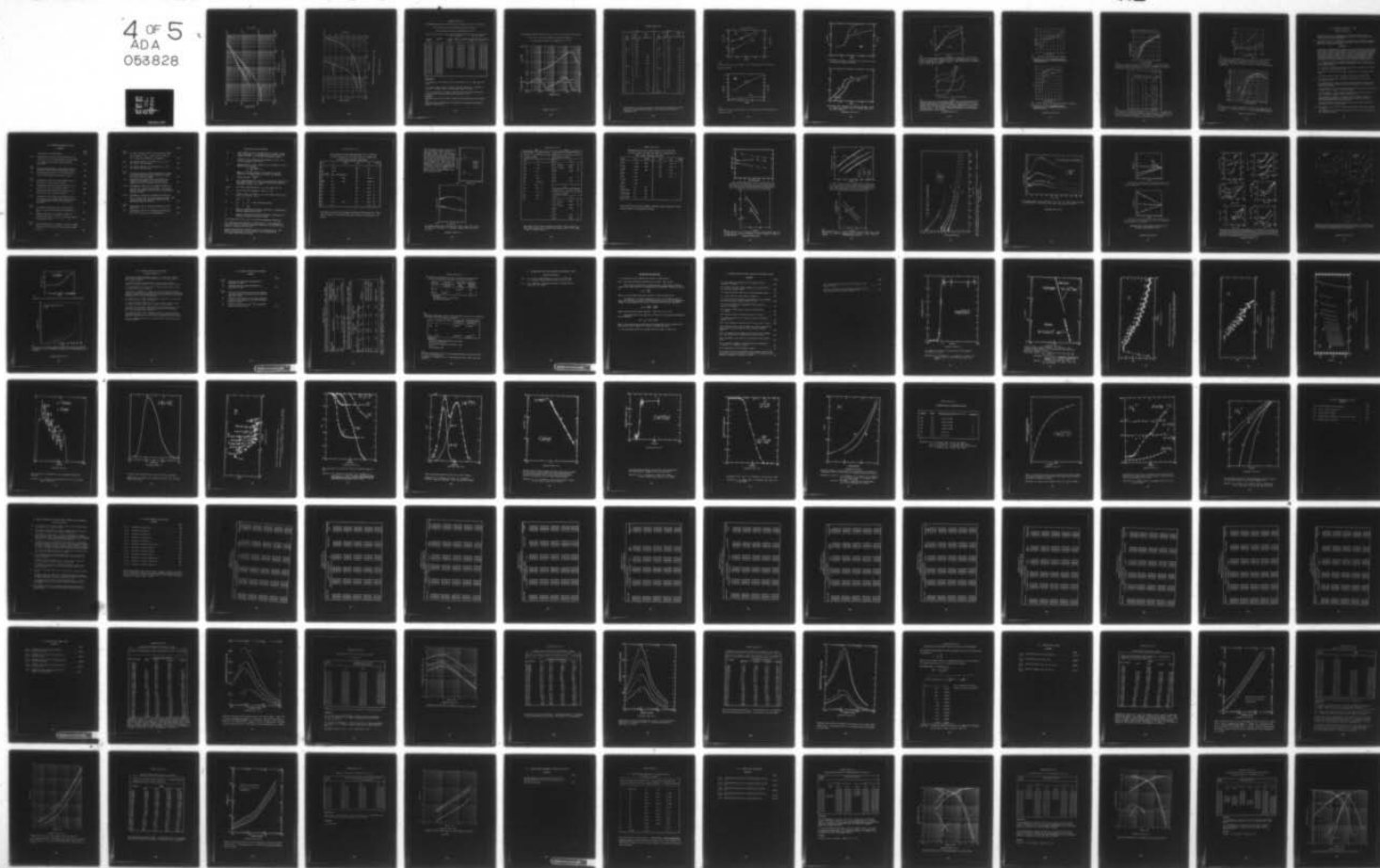
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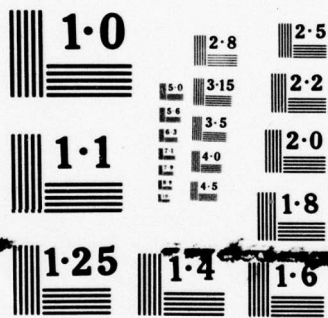
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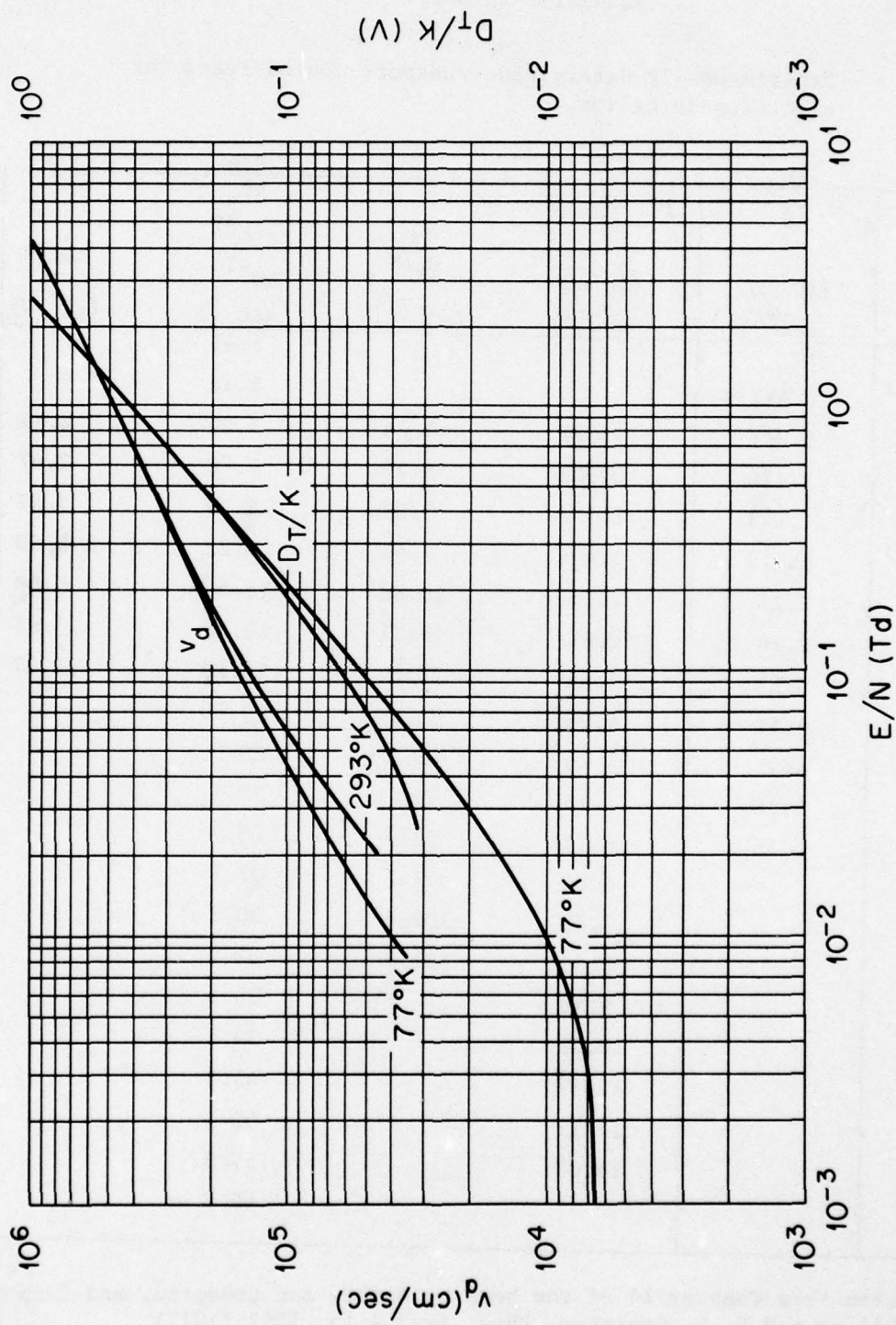
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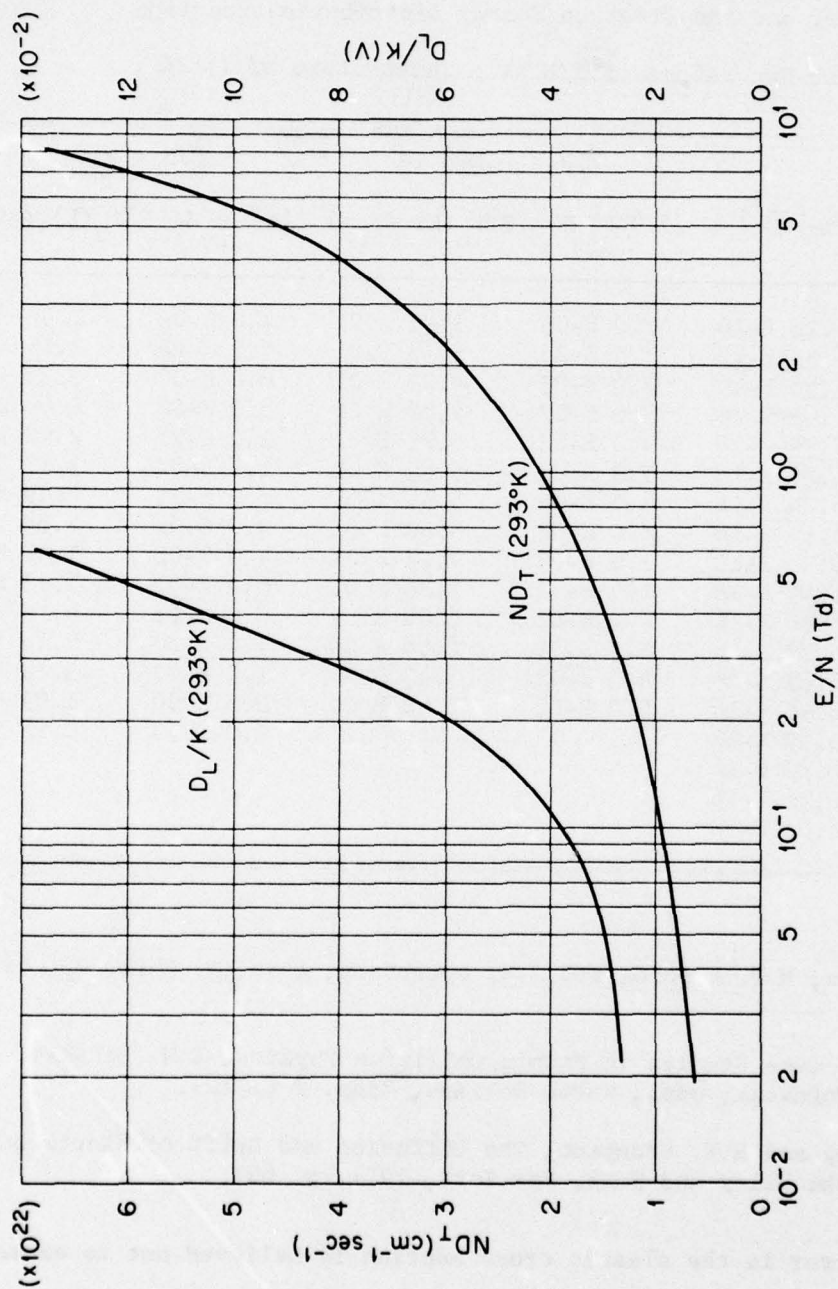




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MICROCOPY RESOLUTION TEST CHART



Electrons in helium: v_d and D_T/K vs. E/N .
Graphical Data E-1.2.



Electrons in helium: D_L/K and ND_T vs. E/N .

Graphical Data E-1.3.

Tabular Data E-1.4.

The Momentum Transfer Cross Section for Elastic Collisions of Electrons
in He, and the Electron Energy Distribution Function
for Two Values of E/N at a Temperature of 77° K

		E/N = 0.008 Td		E/N = 2.0 Td	
Energy (eV)	$\sigma_m (\text{cm}^2)$	Energy (eV)	$E^{1/2} f_0(E) [(\text{eV})^{-1}]^*$	Energy (eV)	$E^{1/2} f_0(E) [(\text{eV})^{-1}]^*$
1.0 E-02	5.21 E-16	1.0 E-03	3.26 E 01	4.0 E-02	1.92 E 01
2.0 E-02	5.35 E-16	1.5 E-03	3.78 E 01	5.0 E-02	2.15 E 01
3.0 E-02	5.46 E-16	2.0 E-03	4.22 E 01	6.0 E-02	2.35 E 01
5.0 E-02	5.62 E-16	3.0 E-03	4.88 E 01	8.0 E-02	2.66 E 01
7.0 E-02	5.74 E-16	4.0 E-03	5.25 E 01	1.0 E-01	2.99 E 01
1.0 E-01	5.86 E-16	5.0 E-03	5.39 E 01	1.5 E-01	3.57 E 01
1.5 E-01	6.04 E-16	6.0 E-03	5.41 E 01	2.0 E-01	4.09 E 01
2.0 E-01	6.16 E-16	8.0 E-03	5.20 E 01	3.0 E-01	4.88 E 01
3.0 E-01	6.35 E-16	1.0 E-02	4.77 E 01	4.0 E-01	5.42 E 01
4.0 E-01	6.49 E-16	1.5 E-02	3.38 E 01	6.0 E-01	6.13 E 01
6.0 E-01	6.66 E-16	2.0 E-02	2.04 E 01	8.0 E-01	6.15 E 01
8.0 E-01	6.77 E-16	3.0 E-02	8.58 E 00	1.0 E 00	5.79 E 01
1.0 E 00	6.85 E-16	4.0 E-02	3.43 E 00	1.5 E 00	3.79 E 01
1.5 E 00	6.96 E-16	5.0 E-02	1.20 E 00	2.0 E 00	1.89 E 01
2.0 E 00	6.99 E-16			3.0 E 00	2.75 E 00
3.0 E 00	6.89 E-16				
4.0 E 00	6.26 E-16				
6.0 E 00	6.01 E-16				

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M.T. Elford, Case Studies in Atomic Collision Physics, E.W. McDaniel and M.R.C. McDowell, eds., North Holland, Chap. 2 (1972).

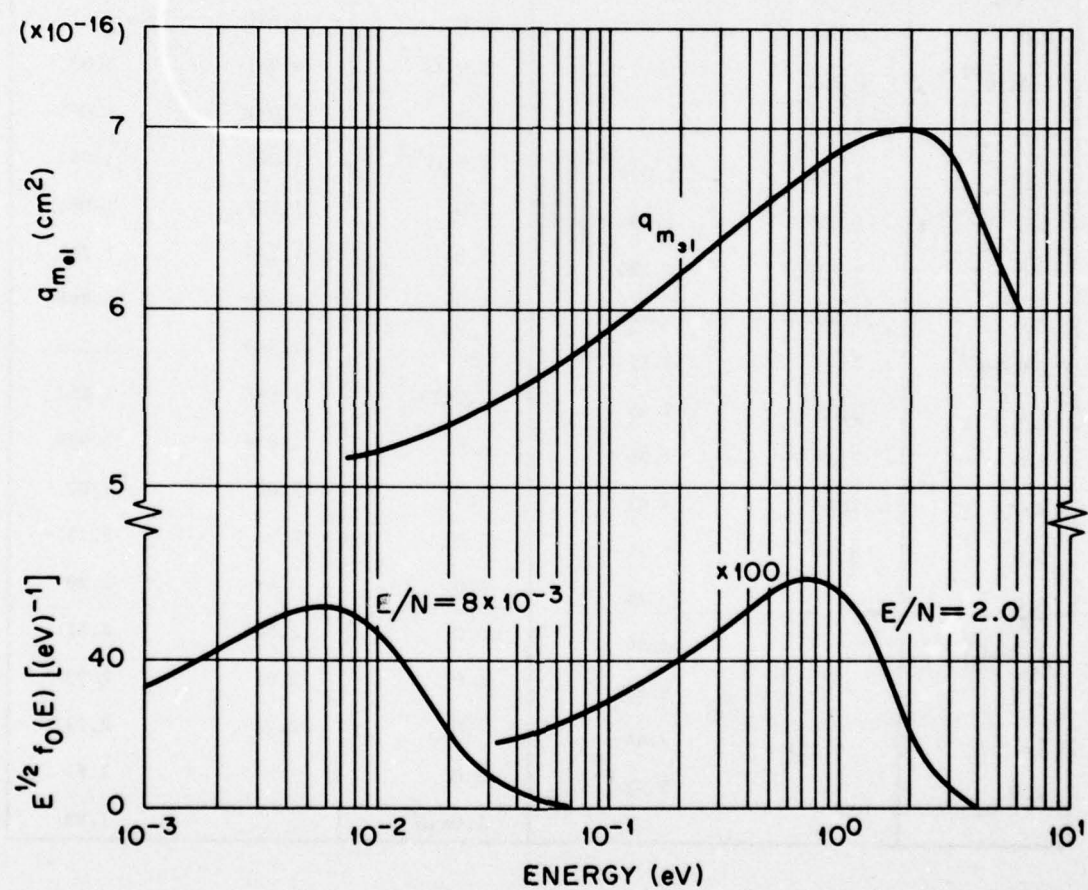
L.G.H. Huxley and R.W. Crompton, The Diffusion and Drift of Electrons in Gases, John Wiley and Sons, New York, 1974, p. 603.

Accuracy:

The total error in the elastic cross section is believed not to exceed $\pm 5\%$.

* $E^{1/2} f_0(E) dE$ is the fraction of electrons in the swarm with energies between E and $E + dE$.

The Momentum Transfer Cross Section for Elastic Collisions of Electrons
in He, and the Electron Energy Distribution Function
for Two Values of E/N at a Temperature of 77° K

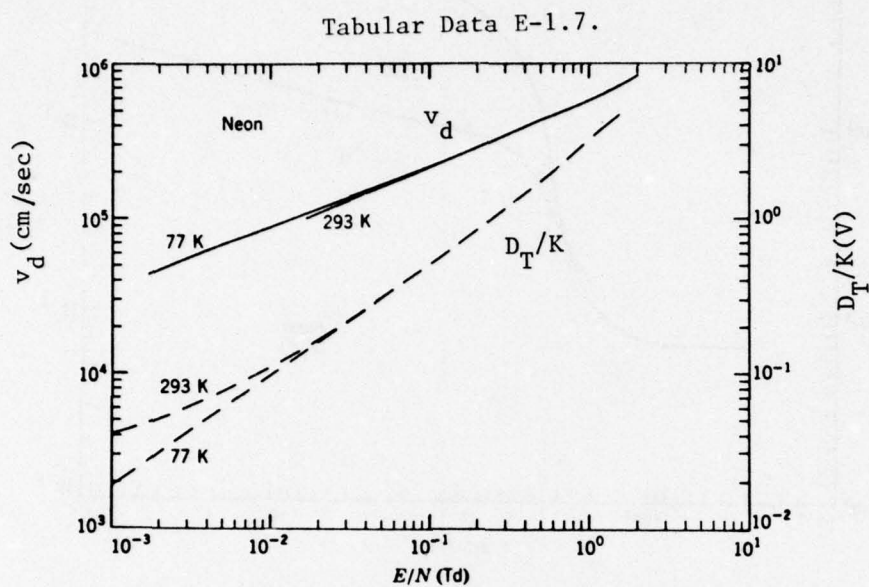


Graphical Data E-1.5.

Tabular Data E-1.6

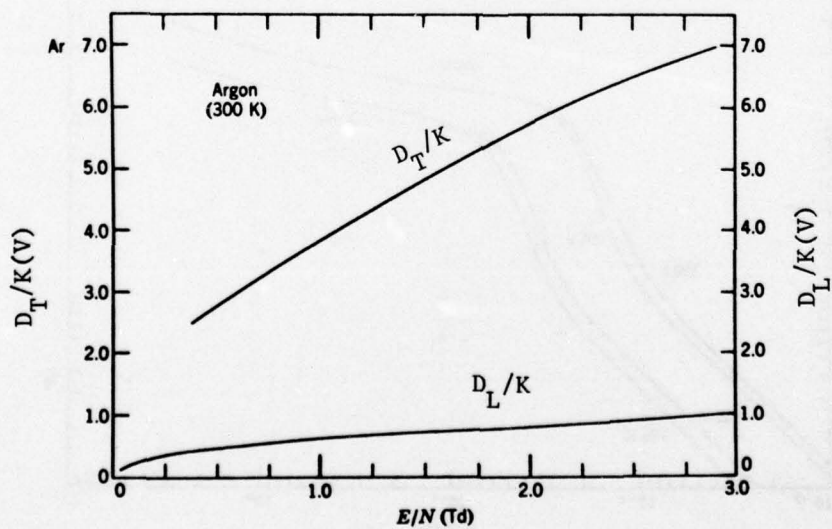
Neon			Argon		
E/N (Td)	77K	293K	E/N (Td)	90K	293K
	$\frac{v_d}{(10^5 \text{ cm sec}^{-1})}$	$\frac{v_d}{(10^5 \text{ cm sec}^{-1})}$		$\frac{v_d}{(10^5 \text{ cm sec}^{-1})}$	$\frac{v_d}{(10^5 \text{ cm sec}^{-1})}$
1.7×10^{-3}	0.437 ⁽¹⁾		2.0×10^{-3}	0.149	
3.0	0.558		3.0	0.286	
5.0	0.683		5.0	0.710	
8.0	0.818		7.0	0.866	
1.0×10^{-2}	0.891		1.0×10^{-2}	0.961	0.935
1.4	1.012		1.4	1.031	1.005
2.0	1.156	1.094	1.7×10^{-2}	1.068	1.047
3.0	1.347	1.293	2.0	1.107	1.084
5.0	1.637	1.590	3.0	1.215	1.205
7.0	1.867	1.826	5.0	1.382	1.368
1.0×10^{-1}	2.15	2.12	8.0	1.569	1.556
1.4	2.48	2.45	1.0×10^{-1}	1.668	1.654
2.0	2.89	2.86	1.4	1.830	1.820
3.0	3.46	3.43	2.0	2.02	2.00
5.0	4.34	4.31	3.0	2.24	2.23
8.0		5.28	4.0	2.41	2.39
1.0×10^0		5.80	5.0	2.54	2.52
1.4		6.68	6.0	2.65	2.63
1.7		7.44	7.0	2.74	2.73
2.0		8.48	8.0		2.81
			1.0×10^0		2.95

Experimentally determined transport coefficients for electrons in neon and argon. Data taken from Chapter 14 of the book by Huxley and Crompton (1974).



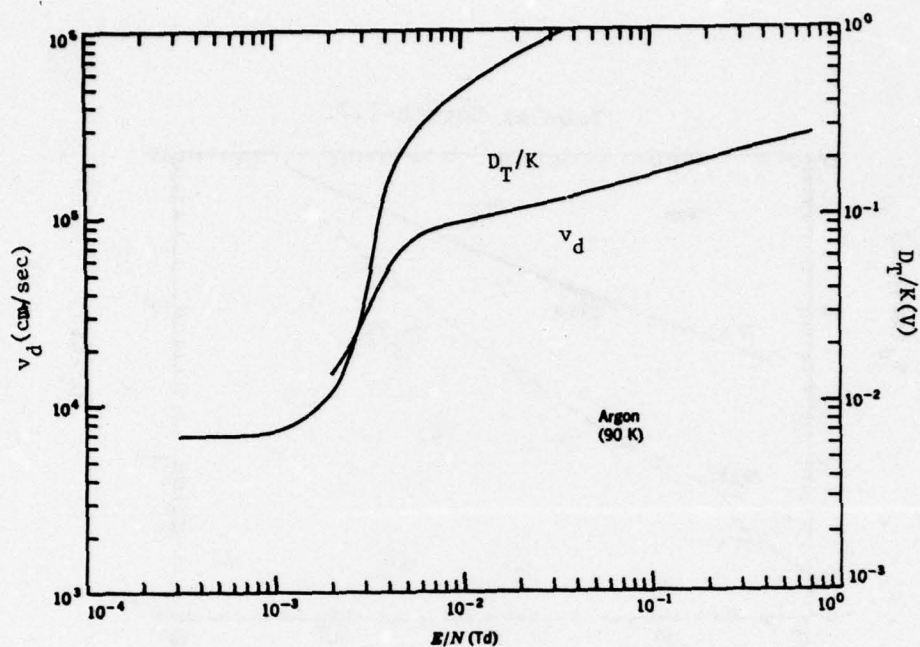
(a)

Electrons in neon: v_d and D_T/K vs. E/N [from the book by Huxley and Crompton (1974)].

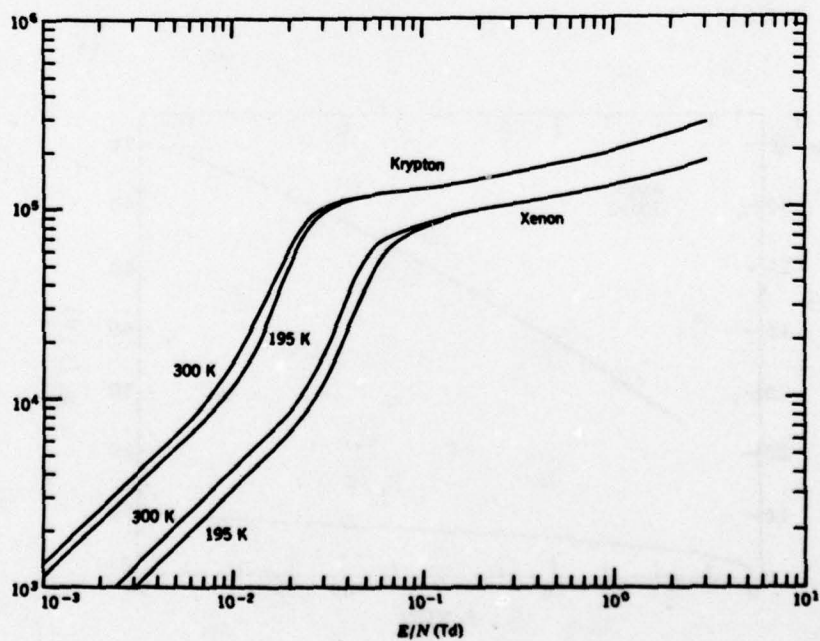


(b)

Electrons in argon: D_T/K and D_L/K vs. E/N [from the book by Huxley and Crompton (1974)].

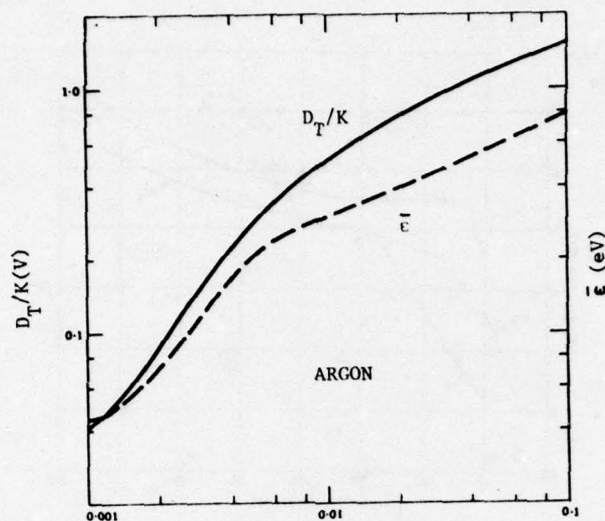


(a) Electrons in argon: v_d and D_T/K vs. E/N [from the book by Huxley and Crompton (1974)].



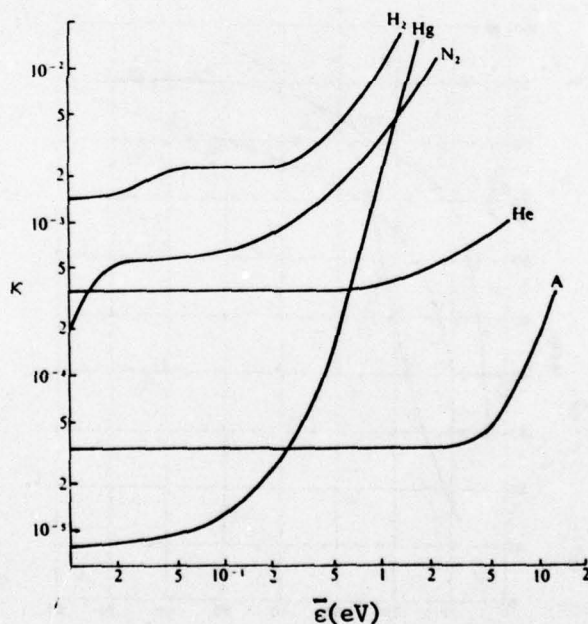
(b) Electron drift velocities in krypton and xenon. [from J.L. Pack, R.E. Voshall, and A.V. Phelps, Phys. Rev., 127, 2084, (1962)].

Graphical Data E-1.8.



(a)

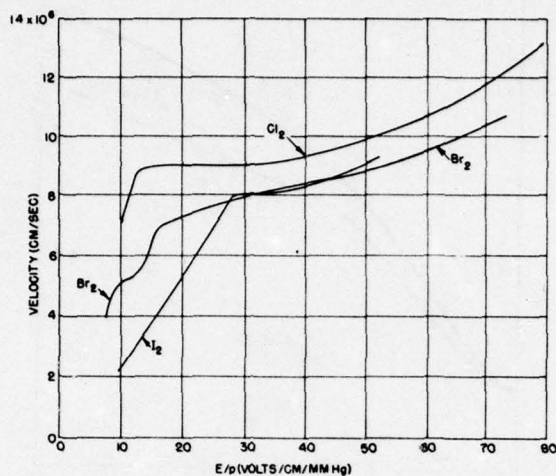
Plots of the measured variation of D_T/K as a function of E/N for electrons in argon at 294 K together with the corresponding E/N variation of the calculated mean electron energy \bar{E} . H.B. Milloy and R.W. Crompton, Aust. J. Phys. 30, 51 (1977).



(b)

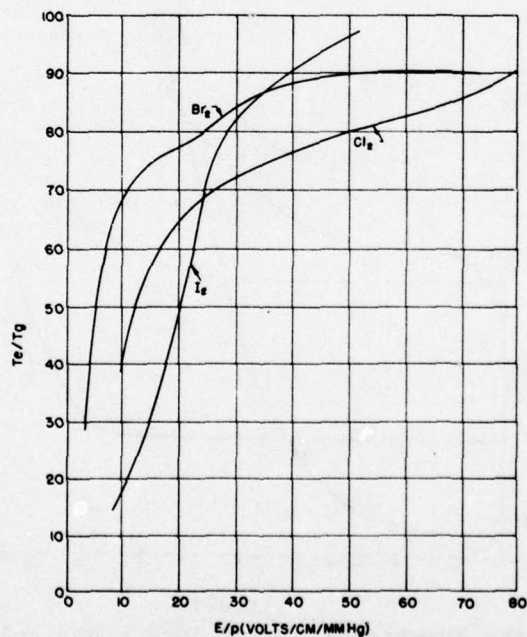
Derived values for the fractional energy loss κ per collision for electrons of mean energy \bar{E} in different gases. The theoretical value of $(8m/3M)$ for elastic collisions is seen to be appropriate at low energy and the onset of inelastic processes differs markedly in atomic and molecular gases. R.N. Franklin, "Plasma Phenomena in Gas Discharges", Clarendon Press, Oxford (1976), p. 7.

Graphical Data E-1.9.



(a) Drift velocity of electrons in the halogens.

R. H. Healey and J. W. Reed, The Behavior of Slow Electrons in Gases, Amalgamated Wireless, Ltd., Sydney (1941), p. 53.

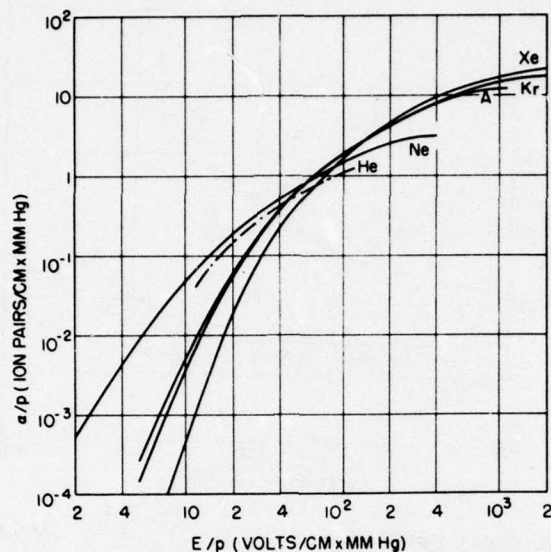


(b) Ratio of electron to gas temperature in Br₂, Cl₂, and I₂.

R. H. Healey and J. W. Reed, The Behavior of Slow Electrons in Gases, Amalgamated Wireless, Ltd., Sydney (1941), p. 52.

Graphical Data E-1.10.

Tabular and Graphical Data E-1.11.



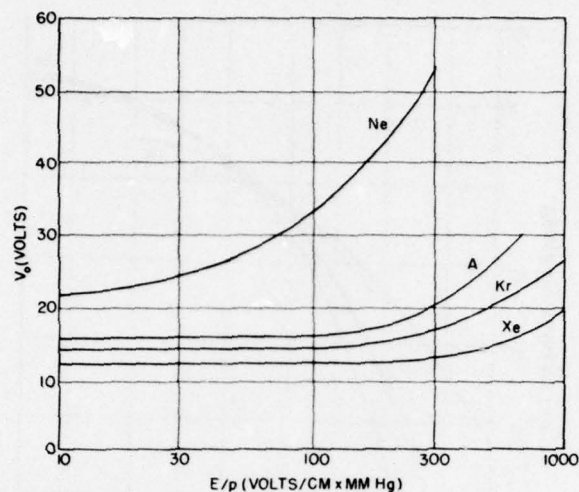
(a)

The first Townsend ionization coefficient, α , in the noble gases, divided by the gas pressure, p . A.von Engel, *Handbuch der Physik*, Springer Verlag, Berlin (1956) Vol. 21, p. 504.

Gas	A	B	Range of validity
	$\frac{\text{ion pairs}}{\text{cm x mm Hg}}$	$\frac{V}{\text{cm x mm Hg}}$	$\frac{V}{\text{cm x mm Hg}}$
H ₂	5	130	150- 600
N ₂	12	342	100- 600
O ₂	-	-	-
CO ₂	20	466	500-1000
air	15	365	100- 800
H ₂ O	13	290	150-1000
HCl	25	380	200-1000
He	3	34 (25)	20- 150 (3-10)
Ne	4	100	100- 400
A	14	180	100- 600
Kr	17	240	100-1000
Xe	26	350	200- 800
Hg	20	370	200- 600

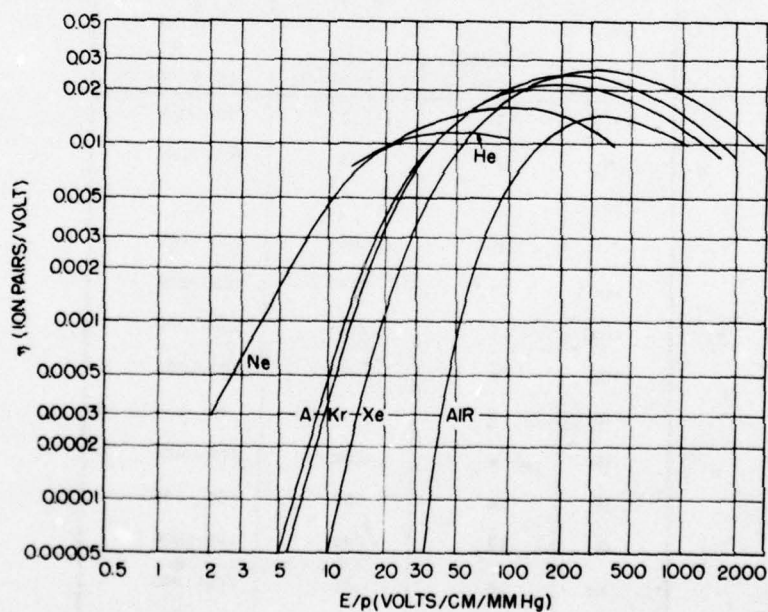
(b)

Constants A and B in the equation $\alpha/p = A e^{-B/(E/p)}$. Von Engel, loc. cit., pg.518. An electron creates α new electrons in a path one cm. long in the field direction. If the electron concentration is n_0 at $x = 0$, then the concentration at depth x is $n = n_0 e^{\alpha x}$.



(a)

The factor V_0 in the equation $i = i_0 e^{\eta(V-V_0)}$. This equation describes the growth of a Townsend avalanche by the fall of electrons through the potential V . The correction factor V_0 accounts for the finite distance required to achieve steady-state conditions.



(b)

Ionizations per volt per mm Hg at 0°C for the rare gases and air.
 $\eta = \alpha/E$. M. J. Druyvesteyn and F. M. Penning, Revs. Mod. Phys. 12, 87 (1940).

Graphical Data E-1.12.

E-2. TRANSPORT PROPERTIES OF IONS

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H. W. Ellis, R. Y. Pai, I. R. Gatland, E. W. McDaniel, R. Wernlund, and M. J. Cohen, "Ion Identity and Transport Properties in CO_2 Over a Wide Pressure Range," J. Chem. Phys., Vol. 64, pg. 3935 (1976).

D,R H. W. Ellis, R. Y. Pai, E. W. McDaniel, E. A. Mason, and L. A. Viehland, "Transport Properties of Gaseous Ions Over a Wide Energy Range," Atomic Data and Nuclear Data Tables, Vol. 17, pgs. 177-210 (1976).

ABSTRACT

A compilation of experimental data is presented for the mobilities of mass-identified ions in neutral gases at room temperature as a function of the ionic energy parameter E/N , the ratio of electric field strength to neutral gas number density. The literature has been covered to February 1976. In addition, a recently developed theory of gaseous ion mobility is used to compute, for each ion-gas combination, the zero-field reduced mobility as a function of the common ion-gas temperature. Finally, it is shown how the tabulated data can be used to estimate the ionic diffusion coefficients and to obtain information about the ion-neutral interaction potential.

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I.R. Gatland, et al., "Interaction Potentials for $\text{Cs}^+ - \text{Ar}$, $\text{Cs}^+ - \text{Kr}$, and $\text{Cs}^+ - \text{Xe}$ ", Jour. Chem. Phys. (1978).

E-2. TRANSPORT PROPERTIES OF IONS

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DEFINITIONS AND RELATIONSHIPS

- \vec{v}_d = drift velocity of ion = average velocity of drift of ion along field lines in a gas exposed to a constant, uniform electric field \vec{E} . v_d is usually expressed in cm/sec.
- K = mobility of ion, defined by the equation $\vec{v}_d = K \vec{E}$. K is usually expressed in $\text{cm}^2/\text{V-sec}$.
- K_o = reduced mobility of ion = mobility of ion reduced to S.T.P., defined by the equation
- $$K_o = \frac{P}{760} \frac{273.16}{T} K,$$
- where p is the gas pressure in torr and T is the gas temperature in degrees Kelvin at which K was measured.
- P_o = reduced pressure = $\frac{273.16}{T} P$.
- E/N = ionic energy parameter = ratio of electric field intensity to gas number density. E/N is usually expressed in units of $(\text{volts/cm}) / (1/\text{cm}^3) = \text{V} - \text{cm}^2$.
- $K_o(0)$ = zero-field reduced mobility = K_o in the limit $E/N \rightarrow 0$.
- Td = unit of E/N , the "Townsend" = $10^{-17} \text{ V} - \text{cm}^2$.
- v_d = $0.0269 \times (E/N) \times K_o$ where v_d is in 10^4 cm/sec , E/N is in Td , and K_o is in $\text{cm}^2/\text{V} - \text{sec}$.
- \vec{D} =
$$\begin{vmatrix} D_T & 0 & 0 \\ 0 & D_T & 0 \\ 0 & 0 & D_L \end{vmatrix}$$
 = ionic diffusion tensor.
- D_L = (scalar) longitudinal diffusion coefficient = coefficient of diffusion along electric field.
- D_T = (scalar) transverse diffusion coefficient = coefficient of diffusion transverse to electric field.

In the limit $E/N \rightarrow 0$, $D_L = D_T = D$, the scalar diffusion coefficient.

For a particular ionic species in a given gas at a given temperature, the drift velocity, mobility, diffusion coefficients, and average ionic energy are functions of E/N alone.

General reference which contains much data not presented here: "The Mobility and Diffusion of Ions in Gases," by E.W. McDaniel and E.A. Mason, Wiley, New York (1973).

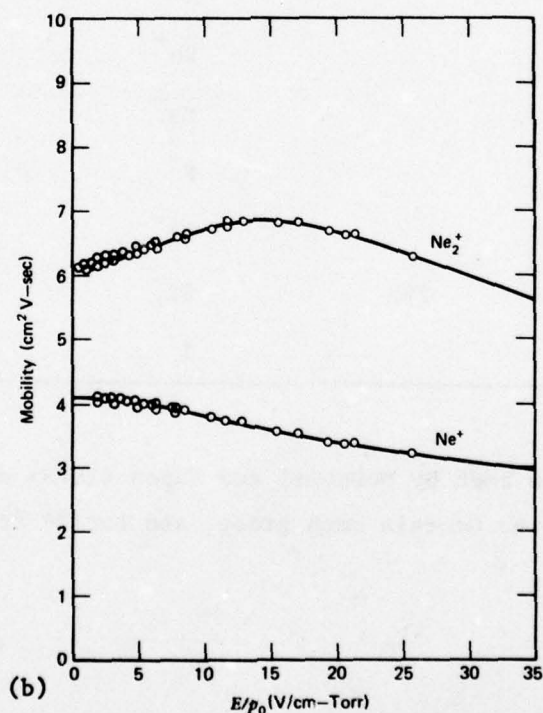
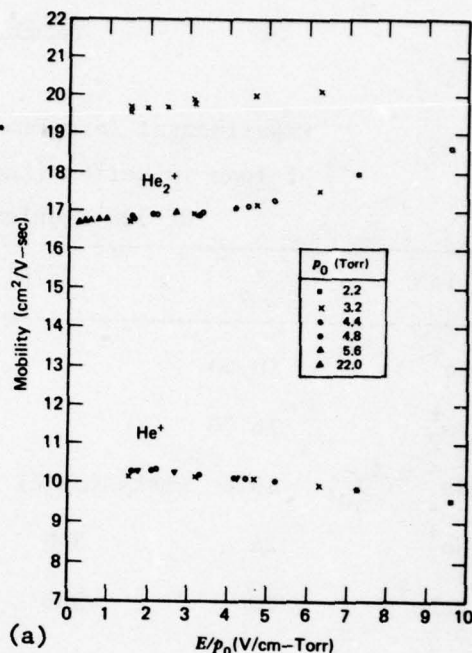
Tabular Data E-2.1.

Experimental Zero-Field Reduced Mobility K_0 in $\text{cm}^2/\text{V-sec}$
of Ions in Helium (the data were taken at a temperature
of 300°K unless otherwise specified)

Ion	K_0	T(°K)	Ion	K_0	T(°K)
He^+	10.40		N_2^+	19	
He_2^+	16.70		O^+	22	
$\text{He}_2^{+m} (^4\Sigma_u^+)$	19.6 (metastable)		O_2^+	21	
Ne^+	24	380	Li^+	23.06	*
HeNe^+	20	380	Na^+	22.64	*
Ne_2^+	17.5		K^+	21.6	*
Ar^+	19.5		Rb^+	20.0	*
Kr^+	20.2		Cs^+	18.2	*
Xe^+	18		F^-	29.5	**
H^+	31.8		Cl^-	20.3	**
Hg^+	19.4	292	Br^-	18.8	**
N^+	20		I^-	16.3	**

Data taken from the book by McDaniel and Mason (1973) except for * from various papers by the Georgia Tech group, and for ** from Dotan et al. (1977).

The reduced mobilities of three helium ions in helium at 300°K plotted as functions of E/p_0 . [E.C. Beaty and P.L. Patterson (1965), Phys. Rev. 137, A346. DT]. The mass of the slowest ion was shown to be 4 amu and the mass of both the faster ions was shown to be 8 amu by J.M. Madson, H.J. Oskam, and L.M. Chanin (1965), Phys. Rev. Letters 15, 1018-DTMS. It has been suggested that the fastest ion is the metastable $^4\Sigma_u^+$ state of He_2^+ by E.C. Beaty, J.C. Browne, and A. Dalgarno (1966), Phys. Rev. Letters 16, 723.



The reduced mobilities of Ne^+ and Ne_2^+ ions in neon as functions of E/p_0 [E.C. Beaty and P.L. Patterson (1968), Phys. Rev. 170, 116. DT].

Graphical Data E-2.2.

Tabular Data F-2.3.

(a)		(b)		
Experimental Zero-Field Reduced Mobility K_0 in $\text{cm}^2/\text{V-sec}$ of Ions in Neon at 300°K		Experimental Zero-Field Reduced Mobility K_0 in $\text{cm}^2/\text{V-sec}$ of Ions in Krypton at 300°K		
Ion	K_0	Ion	K_0	
Ne^+	4.07	$\text{Kr}^+ (^2\text{P}_{3/2})$	0.848	**
Ne_2^+	6.14	$\text{Kr}^+ (^2\text{P}_{1/2})$	0.876	**
He^+	17.2	Kr_2^+	0.995	**
He_2^+	9.3	K^+		
Hg^+	5.95	Rb^+	1.45	*
N_2^+	8.9 ± 0.6	Cs^+	1.30	*
Li^+	10.7 *	(c)		
Na^+	8.27 *	Experimental Zero-Field Reduced Mobility K_0 in $\text{cm}^2/\text{V-sec}$ of Ions in Xenon at 300°K		
K^+	7.43 *	Ion	K_0	
Rb^+	6.53 *	$\text{Xe}^+ (^2\text{P}_{3/2})$	0.531	**
Cs^+	6.0 *	$\text{Xe}^+ (^2\text{P}_{1/2})$	0.562	**
		Xe_2^+	0.617	
		K^+		
		Rb^+	1.02	*
		Cs^+	0.817	*

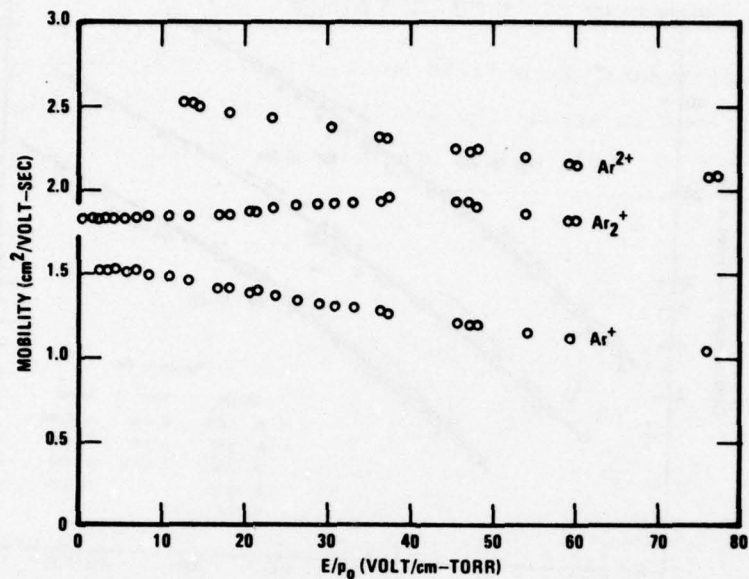
Data taken from the book by McDaniel and Mason (1973) except for * from various papers by the Georgia Tech group, and for ** [H. Helm, J. Phys. B 9, 2931 (1976)].

Tabular Data E-2.4.

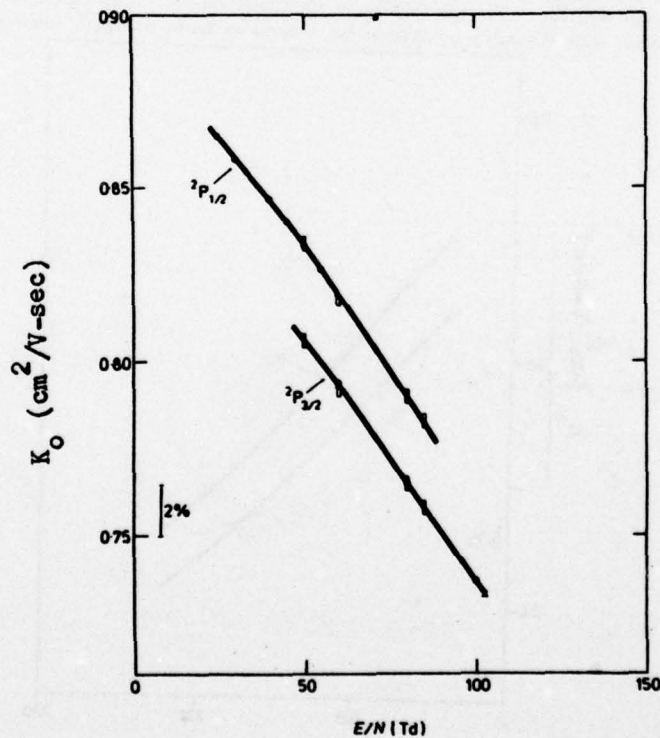
Experimental Zero-Field Reduced Mobility K_o in $\text{cm}^2/\text{V-sec}$
of Ions in Argon (the data were taken at a temperature of
300°K unless otherwise specified)

Ion	K_o	T(°K)	Ion	K_o	T(°K)
Ar^+	1.535	296	Li^+	4.63	*
Ar_2^+	1.833	296	Na^+	3.09	*
Ar^{2+}	2.60	296	K^+	2.66	
Hg^+	1.84		Rb^+	2.26	*
H_3^+	5.75		Cs^+	2.11	*
ArH^+	1.70				
Kr^+	2.30				
H_3O^+	3.0	337			
$\text{H}_3\text{O}^+ \cdot \text{H}_2\text{O}$	2.5	337			
$\text{H}_3\text{O}^+ \cdot 2\text{H}_2\text{O}$	2.2	337			
$\text{H}_3\text{O}^+ \cdot 3\text{H}_2\text{O}$	2.0	337			

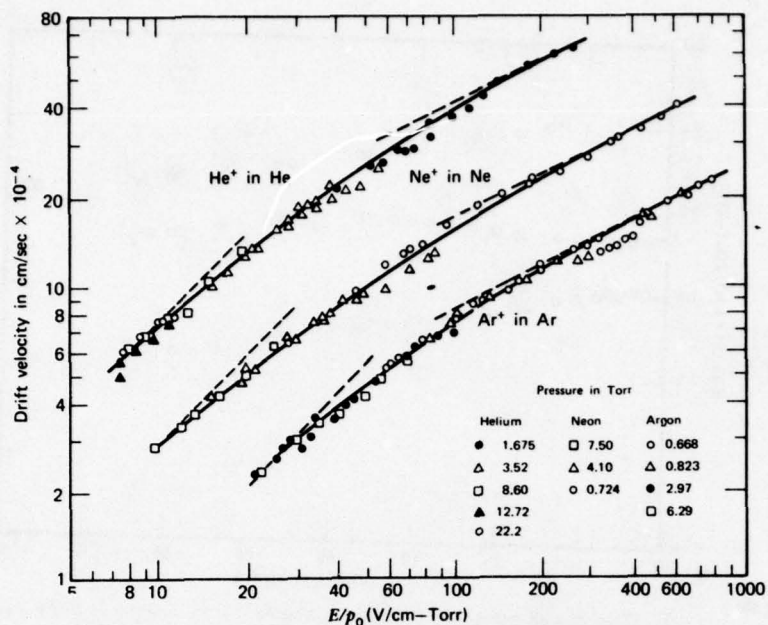
Data taken from the book by McDaniel and Mason (1973) except for * from various papers by the Georgia Tech group.



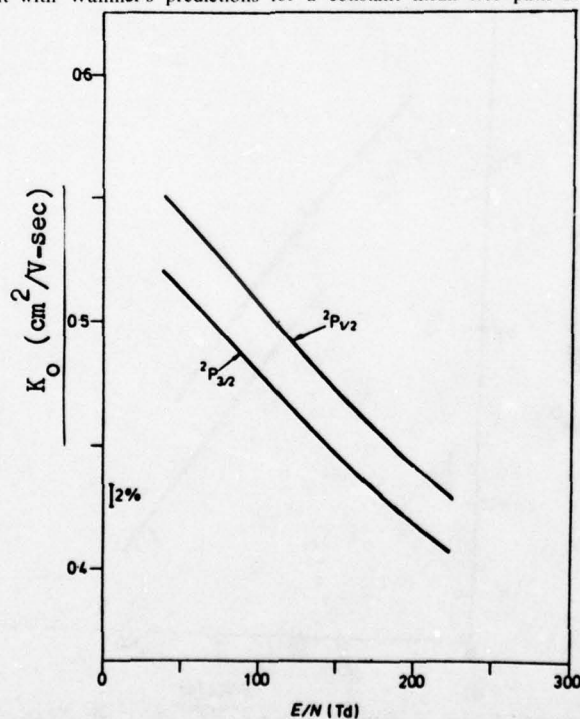
(a) The reduced mobilities of Ar^+ , Ar_2^+ , and Ar_2^{2+} ions in argon at 296°K plotted as functions of E/p_0 [E. C. Beaty (1962), *Proc. 5th Int. Conf. Ionization Phenomena Gases* (Munich, 1961), Vol. 1, p. 183, North-Holland, Amsterdam, DT]. The identities of the ions were established by K. B. McAfee, D. Sipler, and D. Edelson (1967), *Phys. Rev.* **160**, 130—DTMS and by J. M. Madson and H. J. Oskam (1967), *Physics Letters* **25A**, 407—DTMS.



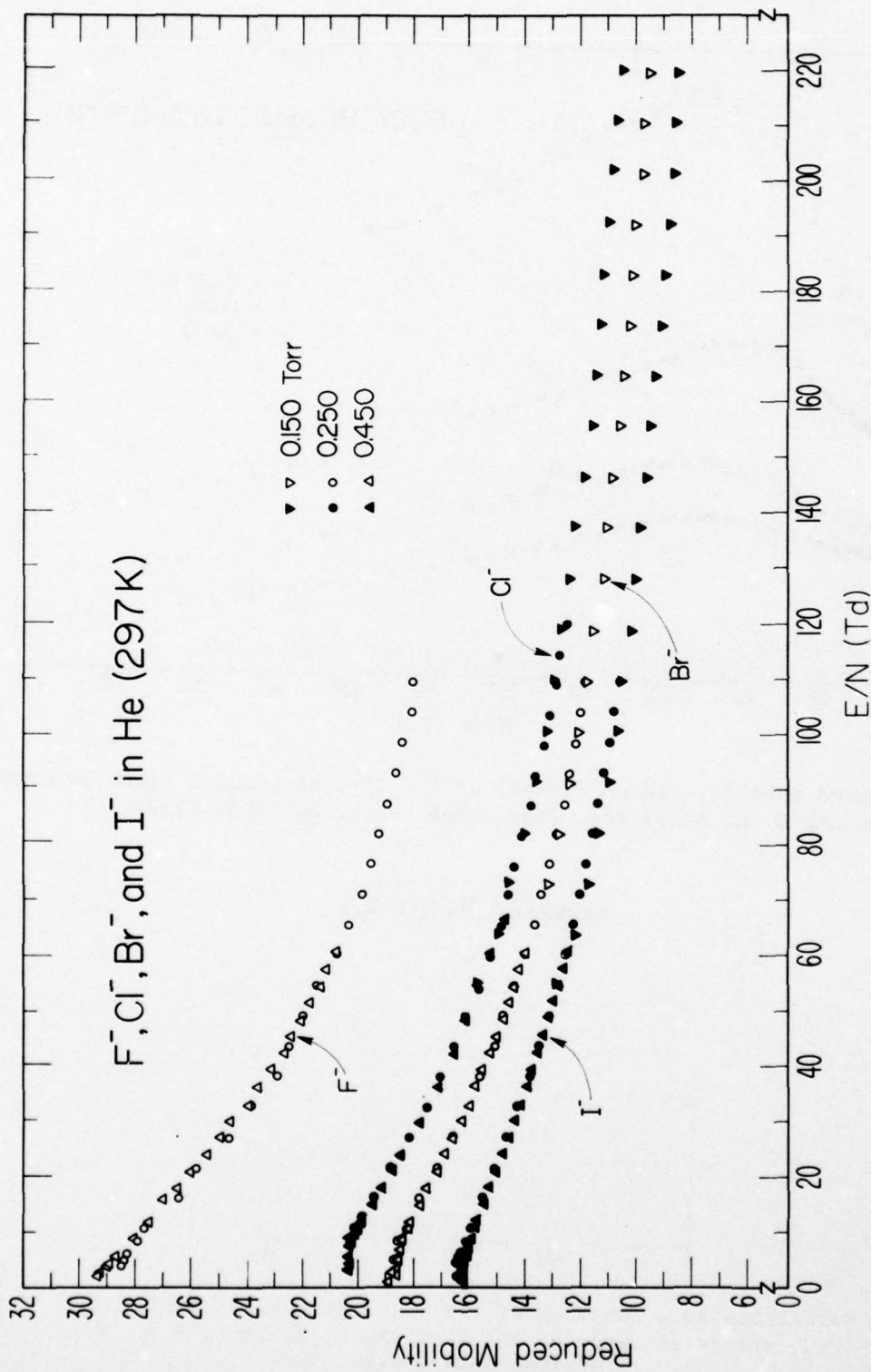
(b) Reduced mobilities as a function of E/N for atomic krypton ions in the $^2P_{1/2}$ and $^2P_{3/2}$ states in krypton at 294°K. H. Helm, *J. Phys. B.* **9**, 2931 (1976). Graphical Data E-2.5.



(a) The drift velocity of He^+ ions in helium at 300°K as a function of E/p_0 . Data on Ne^+ in neon and Ar^+ in argon are included for comparison [J. A. Hornbeck (1951), *Phys. Rev.* **84**, 615. DT]. The broken lines at the left of each experimental curve have slope = 1, whereas the broken lines at the right have slope = $\frac{1}{2}$. The high-field behavior is consistent with Wannier's predictions for a constant mean free path situation

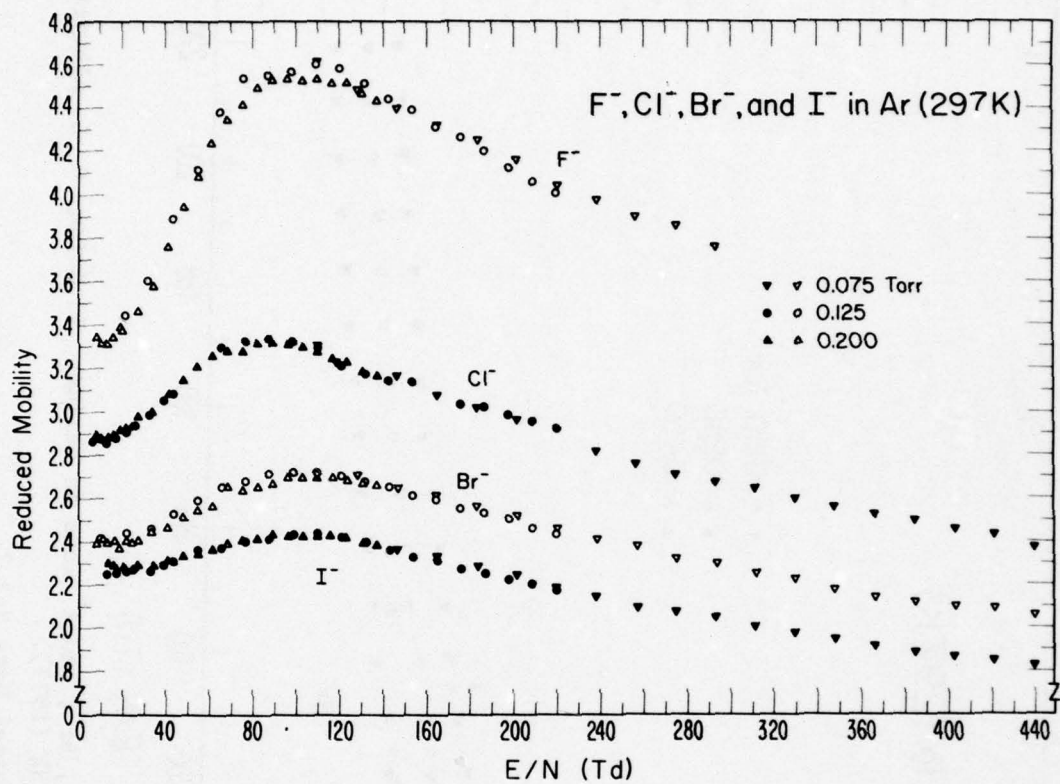


(b) Reduced mobilities as a function of E/N for atomic xenon ions in the $^2P_{1/2}$ and $^2P_{3/2}$ states in xenon at 294 K. H. Helm, *J. Phys. B* **9**, 2931 (1976). Graphical Data E-2.6.



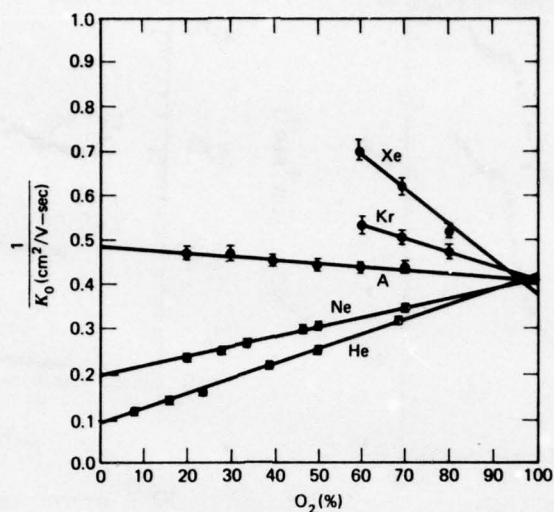
The reduced mobility (in $cm^2/V\text{-sec}$) of F^- , Cl^- , Br^- , and I^- ions in helium. I. Dotan, D. L. Albritton, and F. C. Fehsenfeld, Jour. Chem. Phys. **66**, 2232 (1977).

Graphical Data E-2.7.

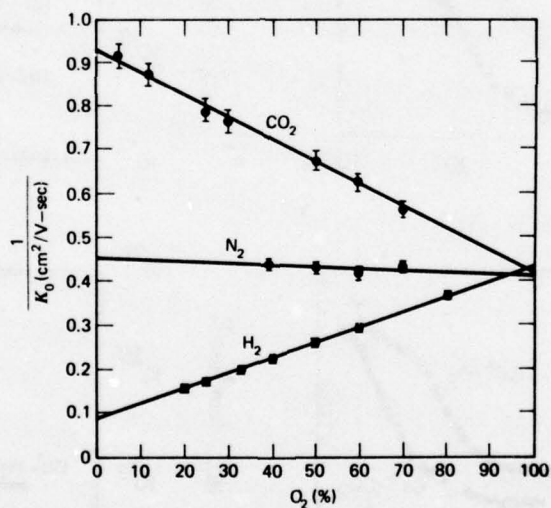


The reduced mobility (in $cm^2/V\text{-sec}$) of F^- , Cl^- , Br^- , and I^- ions in argon. I. Dotan and D. L. Albritton, Jour. Chem. Phys. 66, 5238 (1977).

Graphical Data E-2.8.



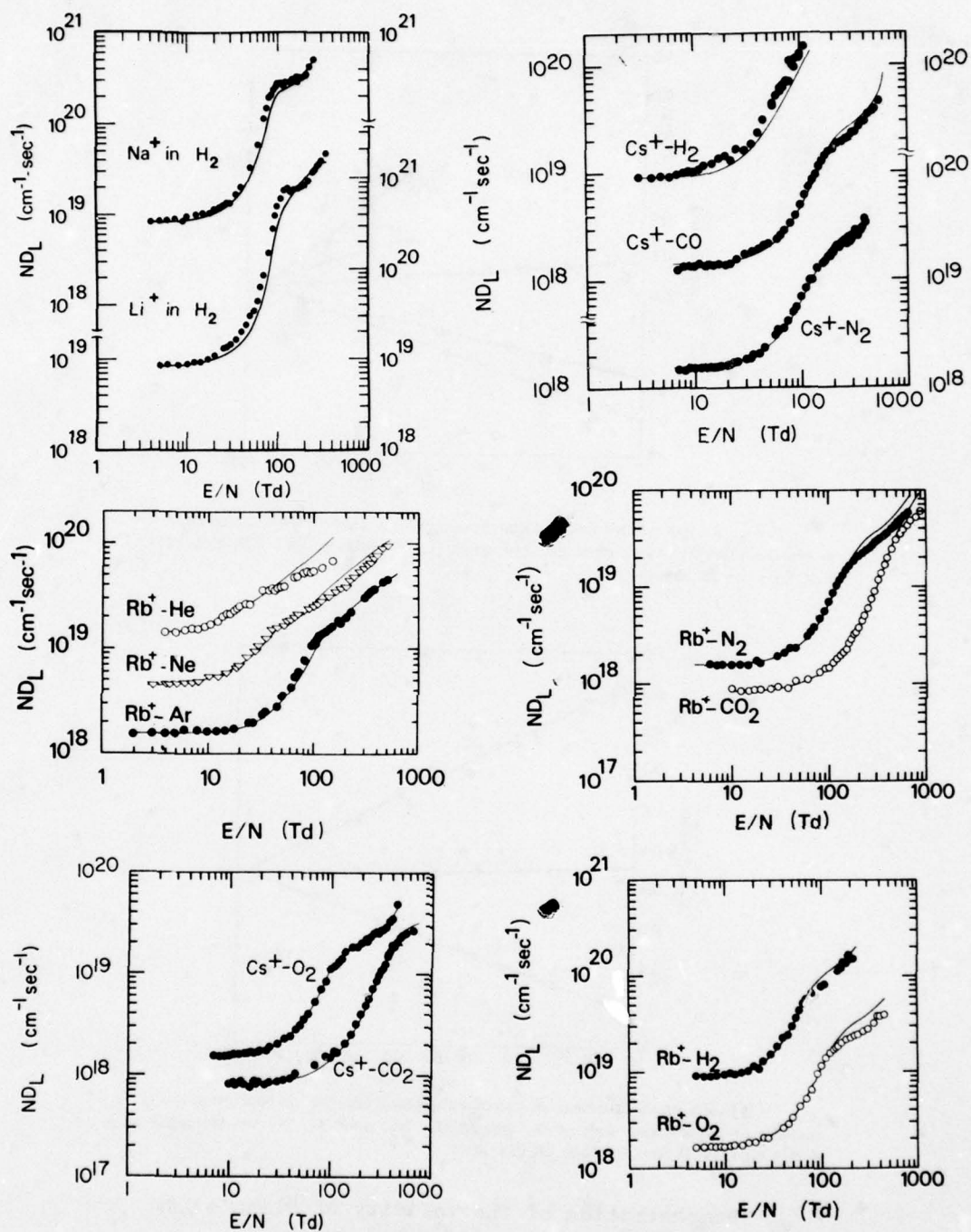
(a) Reciprocal zero-field reduced mobilities for a negative ion believed to be O_3^- in mixtures of oxygen and each of the noble gases. [E. W. McDaniel and H. R. Crane (1957), *Rev. Sci. Instr.* **28**, 634. DT.]



(b) Reciprocal zero-field reduced mobilities for a negative ion believed to be O_3^- in mixtures of oxygen and each of the gases CO_2 , N_2 , and H_2 . [E. W. McDaniel and H. R. Crane (1957), *Rev. Sci. Instr.* **28**, 684. DT.]

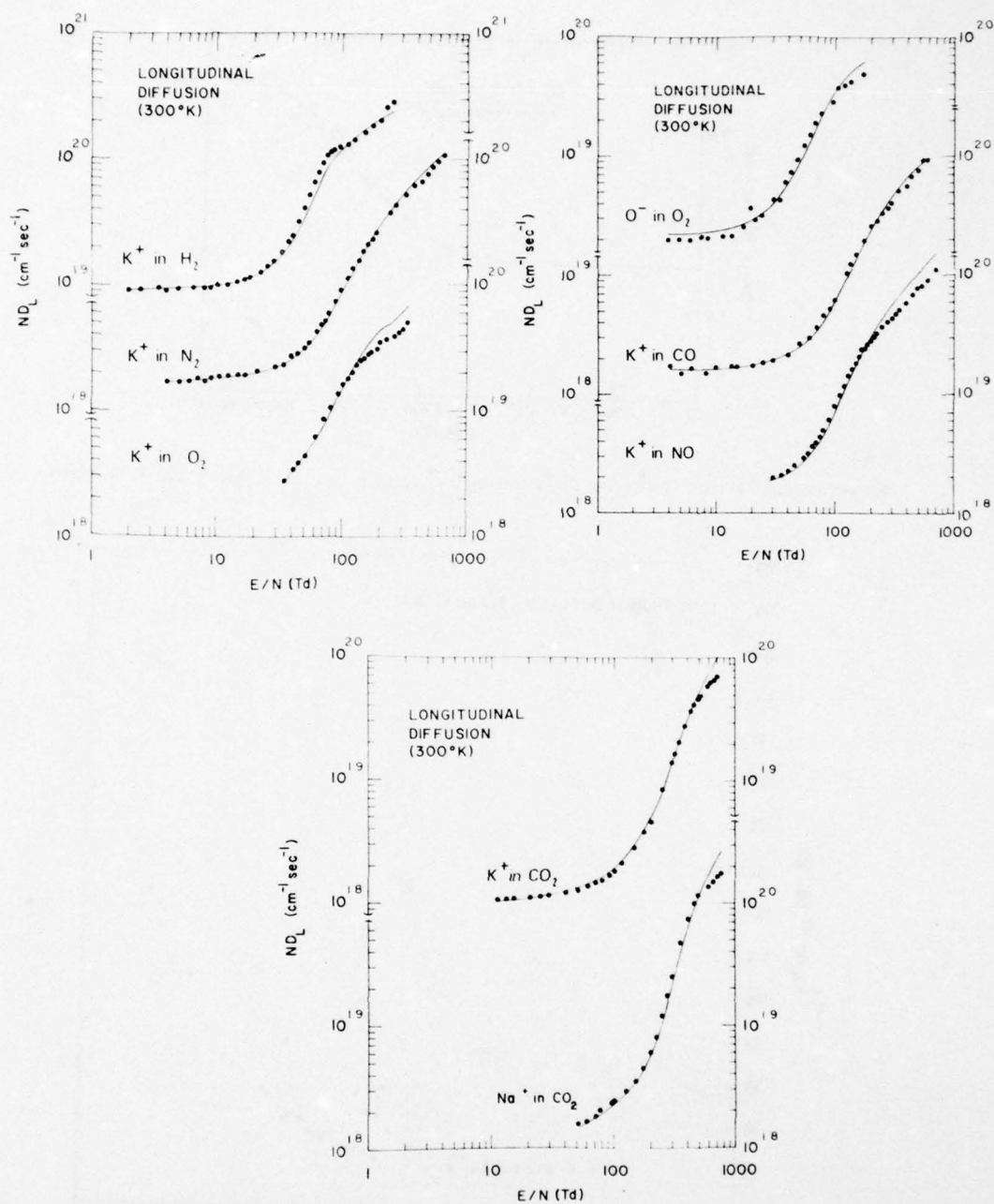
Demonstration of the validity of Blanc's Law
(to within experimental error).

Graphical Data E-2.9.



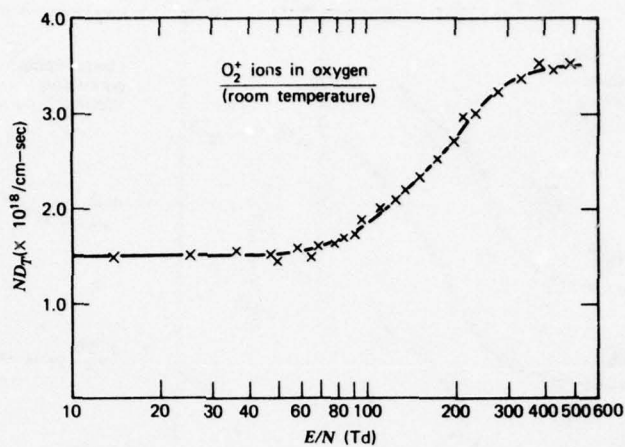
Experimental results (symbols) on longitudinal diffusion of Li^+ , Na^+ , Rb^+ , and Cs^+ ions in gases. The curves indicate the results calculated from the generalized Einstein relation. R. Y. Pai, H. W. Ellis, and E. W. McDaniel, *Jour. Chem. Phys.* **64**, 4239 (1976); H. W. Ellis, M. G. Thackston, R. Y. Pai, and E. W. McDaniel, *Jour. Chem. Phys.* **65**, 3390 (1976); F. L. Eisele, M. G. Thackston, W. M. Pope, I. R. Gatland, H. W. Ellis, and E. W. McDaniel, *Jour. Chem. Phys.* **67**, 1278 (1977).

Graphical Data E-2.10.



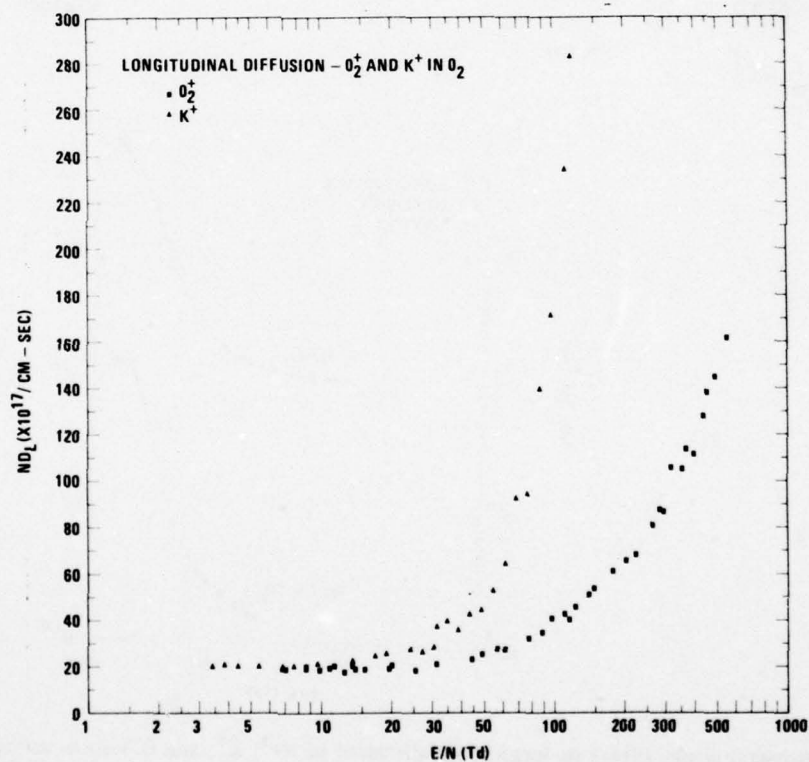
Experimental results (dots) on longitudinal diffusion of Na^+ , K^+ , and O^- ions in various molecular gases. The curves indicate the results calculated from the generalized Einstein relation. R. Y. Pai, H. W. Ellis, G. R. Akridge, and E. W. McDaniel, Phys. Rev. A 12, 1781 (1975).

Graphical Data E-2.11.



(a)

Experimental data on transverse diffusion of O_2^+ ions in O_2 . D. R. Gray and J. A. Rees,



(b)

Experimental results on longitudinal diffusion of O_2^+ and K^+ ions in O_2 at room temperature. R. M. Snuggs, D. J. Volz, J. H. Schummers, D. W. Martin, and E. W. McDaniel, Phys. Rev. A **3**, 477 (1971).

Graphical Data E-2.12.

E-3. TRANSPORT PROPERTIES OF NEUTRALS

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- C.F. Curtiss, "Transport Phenomena in Gases," in H. Eyring (Ed.), "Annual Review of Physical Chemistry," Annual Reviews, Inc., Vol. 18, pg. 125, Palo Alto, California (1967).
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- D T. R. Marrero and E. A. Mason, "Gaseous Diffusion Coefficients," J. Phys. Chem. Ref. Data, Vol. 1, No. 1, pgs. 1-118 (1972).
- E. A. Mason, "Transport in Neutral Gases," in A. R. Hochstim (Ed.), "Kinetic Processes in Gases and Plasmas," pg. 57, Academic, New York (1969).
- E. A. Mason and T. R. Marrero, "The Diffusion of Atoms and Molecules," in D. R. Bates and I. Estermann (Eds.), "Advances in Atomic and Molecular Physics," Vol. 6, pg. 155, Academic, New York (1970).
- E. W. Montroll and M. S. Green, "Statistical Mechanics of Transport and Non-equilibrium Processes," in G. K. Rollefson (Ed.), "Annual Review of Physical Chemistry," Annual Reviews, Inc., Vol. 5, pg. 449, Palo Alto, California (1954).
- H. Moraal, "Quantum Kinetic Theory of Polyatomic Gases," Physics Reports, Vol. 17, pg. 225 (1975).

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Tabular Data E-3.1.

(a) Diffusion Data for Helium Metastables in Helium Gas at 300°K. The Number Density of the Ground State Helium Atoms is N_0 , and D is the Diffusion Coefficient.

Metastable State	$DN_0(\text{cm}^{-1}\text{sec}^{-1})$	Volume loss rate by collisions with neutral Particles
2^1S	$(1.4 \pm 0.2) \times 10^{19}$	Linear: $6 \times 10^{-15} \text{ cm}^3/\text{sec}$
2^3S	$(1.51 \pm 0.08) \times 10^{19}$	$(2.5 \pm 0.3) \times 10^{-34} \text{ cm}^6/\text{sec}$

A. V. Phelps, Phys. Rev. 99, 1307 (1955).

(b) Diffusion Data for Argon Metastables in Argon Gas at 300°K. The Number Density of the Ground State Argon Atoms is N_0 and D is the Diffusion Coefficient.

$DN_0(10^{18} \text{ cm}^{-1}\text{sec}^{-1})$	Two-body loss rate		Three-body loss rate		Reference
	3P_2	3P_0	3P_2	3P_0	
3P_2	3P_0	3P_2	3P_0	3P_2	
1.74	-	1.25	-	0.79	Phelps and Molnar (1953)
1.66	1.77	0.88	5.2	1.7	Ellis and Twiddy (1969)
1.54	-	1.3	-	1.35	Futch and Grant (1956)
1.29	1.03	1.85	1.4	2.9	Sadeghi (1974)

From J.L. Delcroix, C.M. Ferreira, and A. Ricard, "Metastable Atoms and Molecules in Ionized Gases," pp. 194-5, in G. Bekefi (Ed.), "Principles of Laser Plasmas," Wiley, N.Y. (1976).

Tabular Data E-3.2.

- (a) Diffusion coefficients and two- and three-body destruction rates for metastable neon atoms in neon gas at 300 K.

Excited Species	Two-body Destruction Rate (cm ³ /s)	Three-body Rate (cm ⁶ /s)	Diffusion Constant (cm ² /s)
Ne 1s ₅	---	0.5x10 ⁻³³	139
Ne 1s ₃	8.0x10 ⁻¹⁵	---	152

REFERENCE:

A.V. Phelps, Phys. Rev. 114, 1011 (1959);
Phys. Rev. 99, 1305 (1955).

- (b)

Diffusion coefficients and two- and three-body reaction rate constants for krypton metastable atoms in krypton.

State	Dp ₀ (cm ² sec ⁻¹ Torr)	Two-body Rate (cm ³ sec ⁻¹)	Three-body Rate (cm ⁶ sec ⁻¹)
5s ₀₀	49	9.0x10 ⁻¹⁵	53.6x10 ⁻³³
	34		
5s ₁₂	29.3	2.44x10 ⁻¹⁵	25.9x10 ⁻³³

REFERENCE:

R.T. Ku, J.T. Verdeyen, B.E. Cherrington, and J.G. Eden,
Phys. Rev. A 8, 3123 (1973).

C.J. Tracy and H.J. Oskam, Jour. Chem. Phys. 65, 1666
(1976).

Tracy and Oskam (1976).

- (c)

Diffusion coefficient of Xe* (³P₂) metastable atoms in Xe gas at 300 K:
D = (19 ± 2) cm² Torr/sec.

[A. Barbet, N. Sadeghi, and J.C. Pebay-Peyroula, Jour. Phys. B 8, 1776
(1975)].

F. INTERACTIONS WITH STATIC ELECTRIC AND MAGNETIC FIELDS

General References

- D,R R. N. Il'in, "Atomic Physics 3", ed. S. J. Smith and
G. K. Walters, Plenum Press, New York (1973), p. 309.
- D, R E. W. McDaniel, "Collision Phenomena in Ionized Gases,"
Wiley, New York (1964).

DEFINITIONS AND NOTATIONS

F - the electric field, measured in volts/cm or kilovolts/cm.

W(F) - the field ionization probability per second. (See F-5,18)

When a beam of particles is passed through a region with an electric field F, then the fraction of the beam which is transmitted through the region is

$$I(F) = \frac{i(F)}{i_0}$$

where i_0 is the initial beam flux, and $i(F)$ is the attenuated flux.

The addition of a weak alternating field ΔF to the ionizing field F allows the detection, by means of synchronous detection, of the corresponding change in the transmitted flux $\Delta i(F)$, yielding the differential dependence

$$D(F) = \frac{\Delta i(F)}{\Delta F} \approx \frac{di(F)}{dF}$$

which is the field ionization spectrum. (See F-3, 4, 6, 8, 10).

The attenuation of the beam may be related to the ionization probability by the relation

$$I(F) = \sum_k f_k \exp\{-tW_k(F)\}$$

where f_k is the fraction of particles in the beam which are in the k th state, and t is the time of flight for a particle through the field.

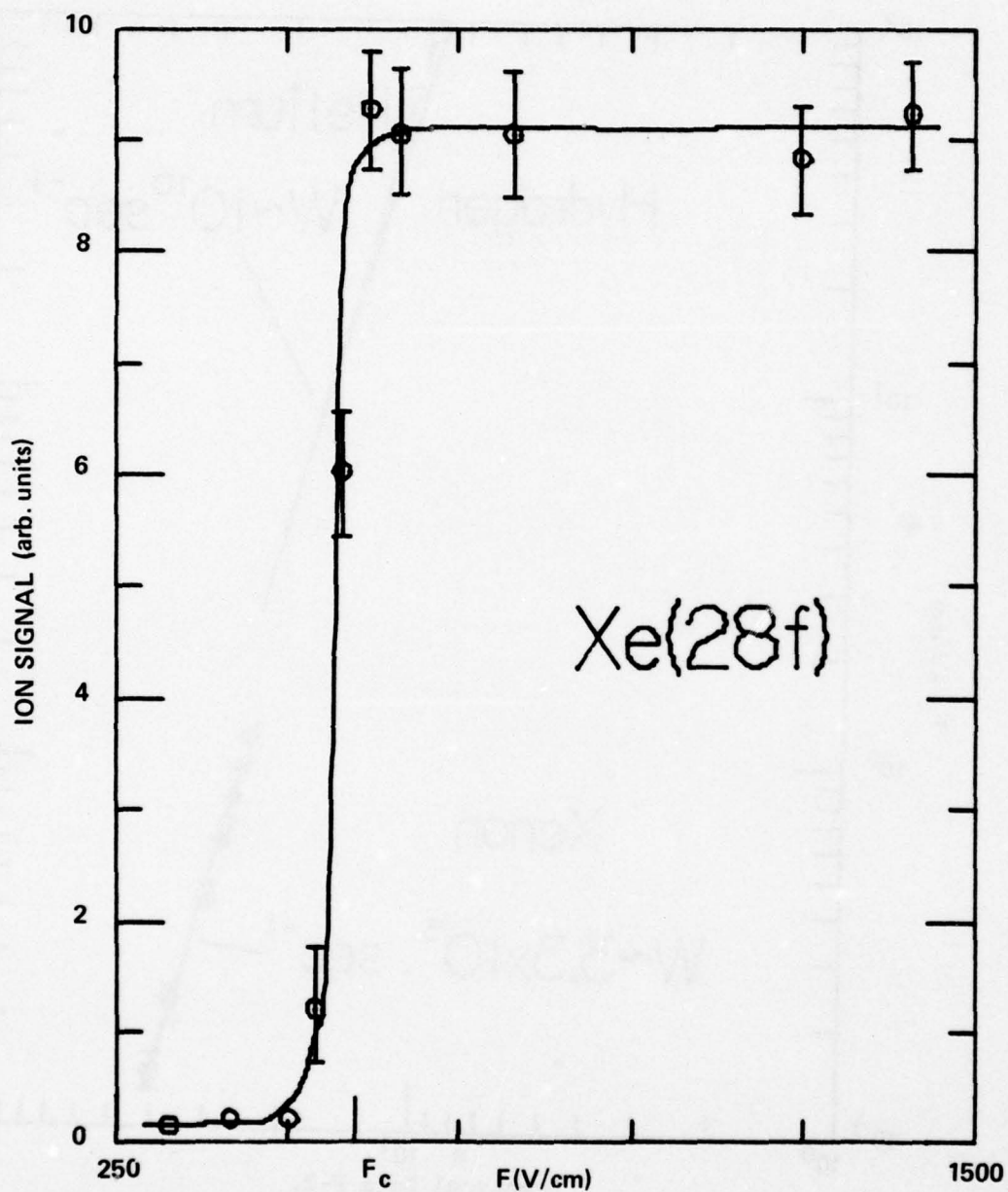
T - the time during which the ionizing field is turned on. (See F-1).

F. INTERACTIONS WITH STATIC ELECTRIC AND MAGNETIC FIELDS

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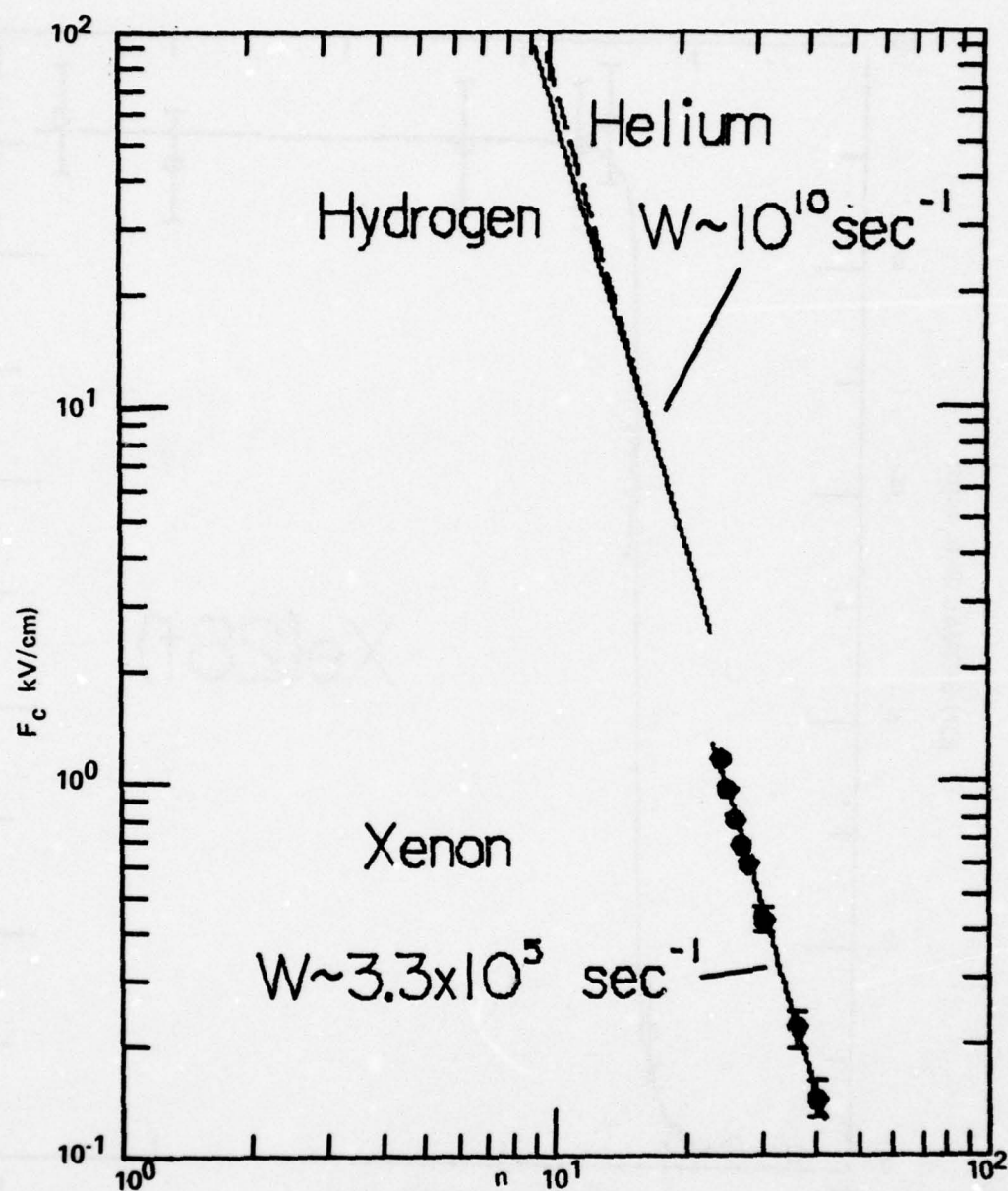
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Graphical Data F-1.

Ion signal as a function of the electric field strength for Xe(28f), $T=3 \mu\text{sec}$.

Reference: R. F. Stebbings, C. J. Latimer, W. P. West, F. B. Dunning, and T. B. Cook, Phys. Rev. A12, 1453 (1975).

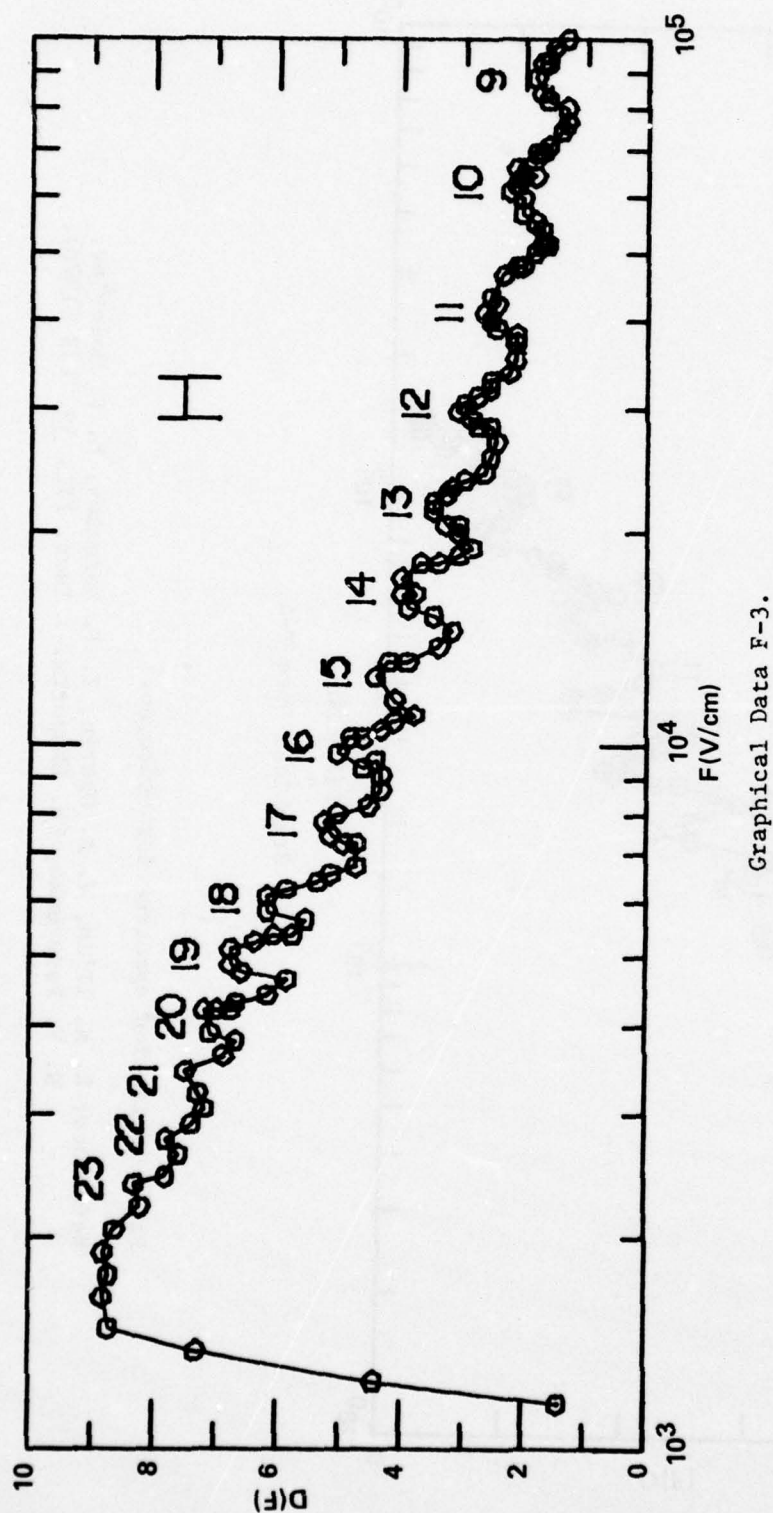


Graphical Data F-2.
Critical electric field strength F_c as a function of the principal quantum number n . The experimental and theoretical results for hydrogen coincide.

References: (Xenon) - R. F. Stebbings et al., Phys. Rev. A12, 1453 (1975).

(Hydrogen) - A. C. Riviere, in Methods of Experimental Physics, ed. B. Bederson and W. Fite, Academic Press, New York, 1968, v. 7A.

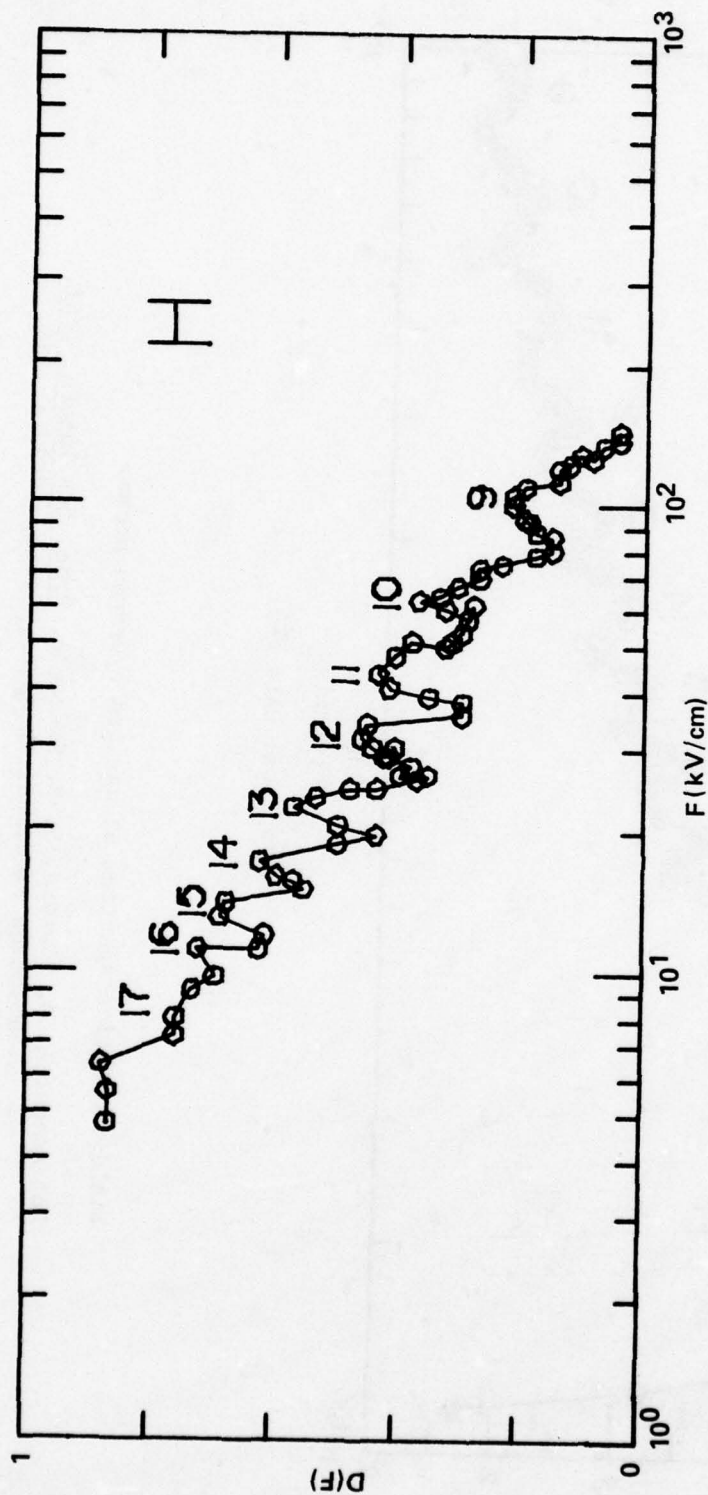
(Helium) - R. N. Il'in et al. Zh. Eksp. i Teor. Fiz. 47, 1234 (1970).



Graphical Data F-3.

Field ionization spectrum of excited hydrogen atoms.

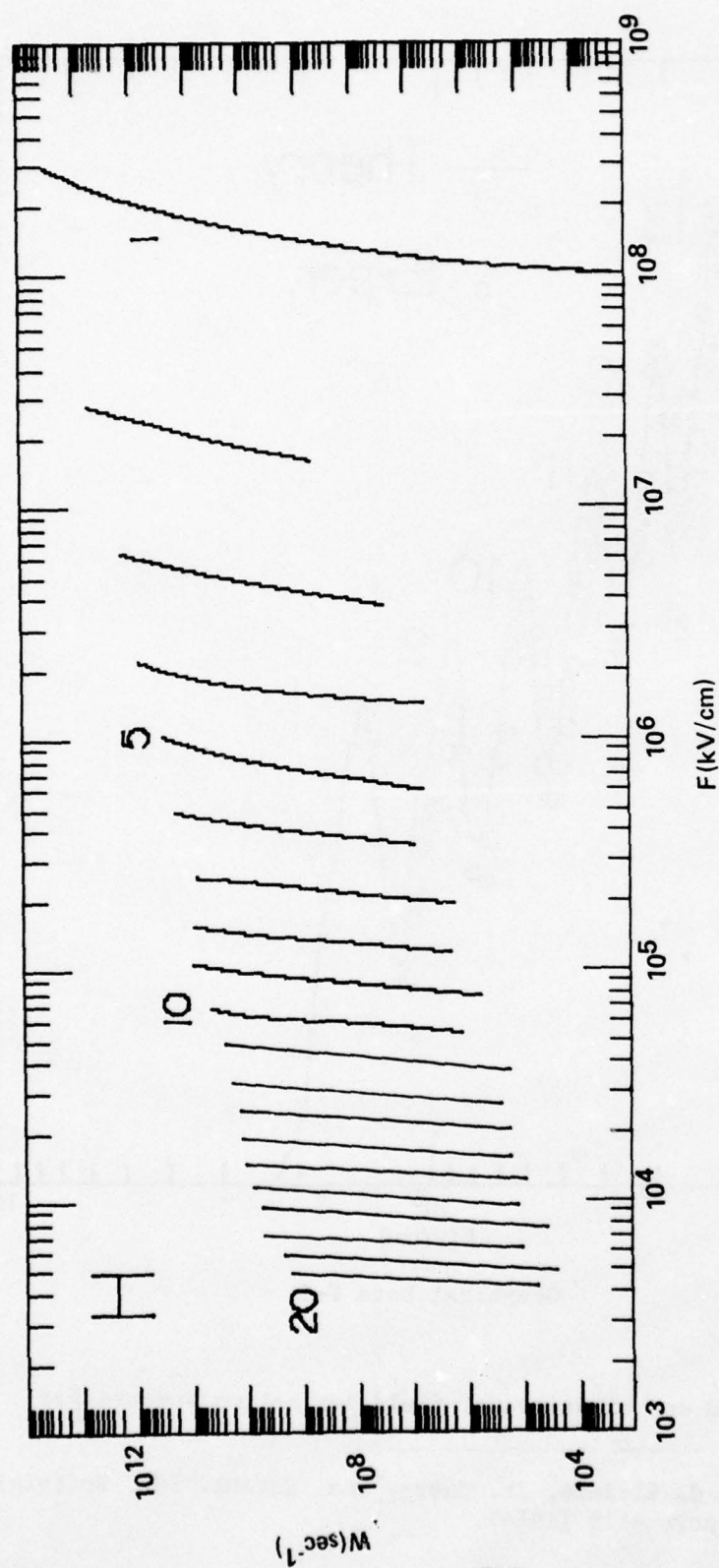
Reference: A. C. Riviere, D. R. Sweetman, Proc. 6th Intern. Conf. Ionization Phenomena in Gases, Paris, 1963, p. 105.



Graphical Data F-4.

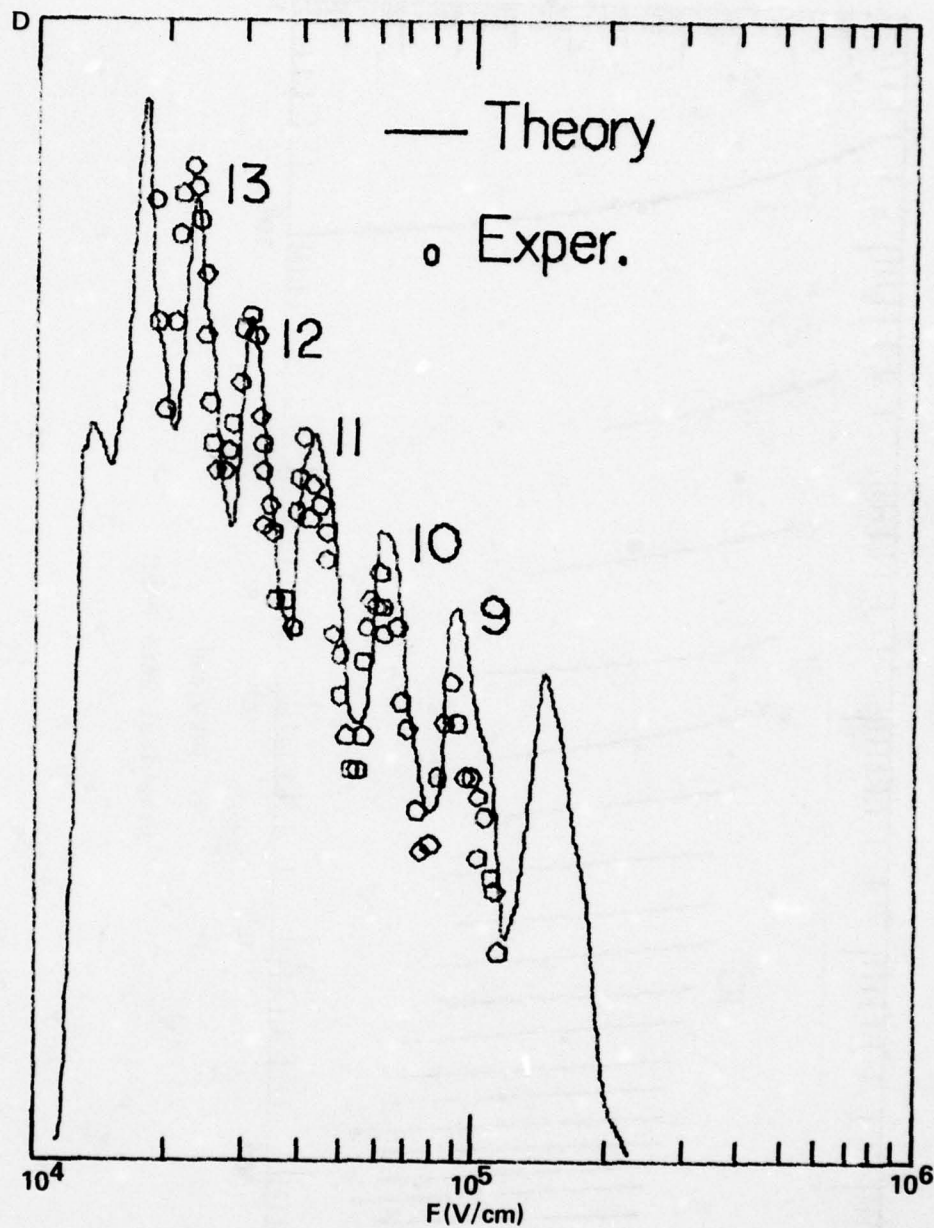
Field ionization spectrum for hydrogen.

Reference: R. N. Litvin, V. A. Oparin, I. T. Serenkov, E. S. Solov'ev,
N. V. Fedorenko, Zh. Eksperim. i Teor. Fiz. 59, 103 (1970).



Graphical Data F-5.

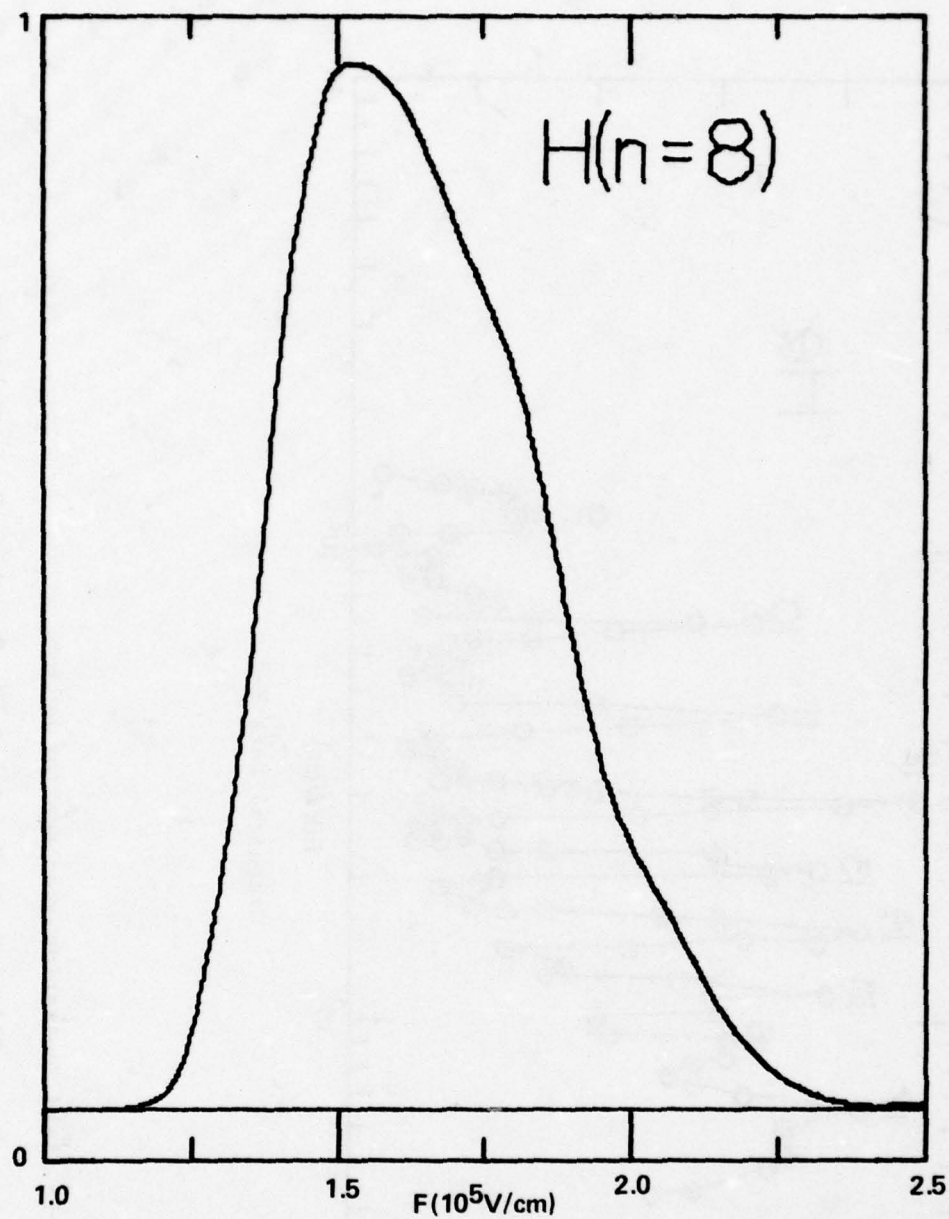
Electric field ionization probability for the hydrogen atom with principal quantum number $1 \leq n \leq 20$.



Graphical Data F-6.

The calculated and experimental field ionization spectra for hydrogen.

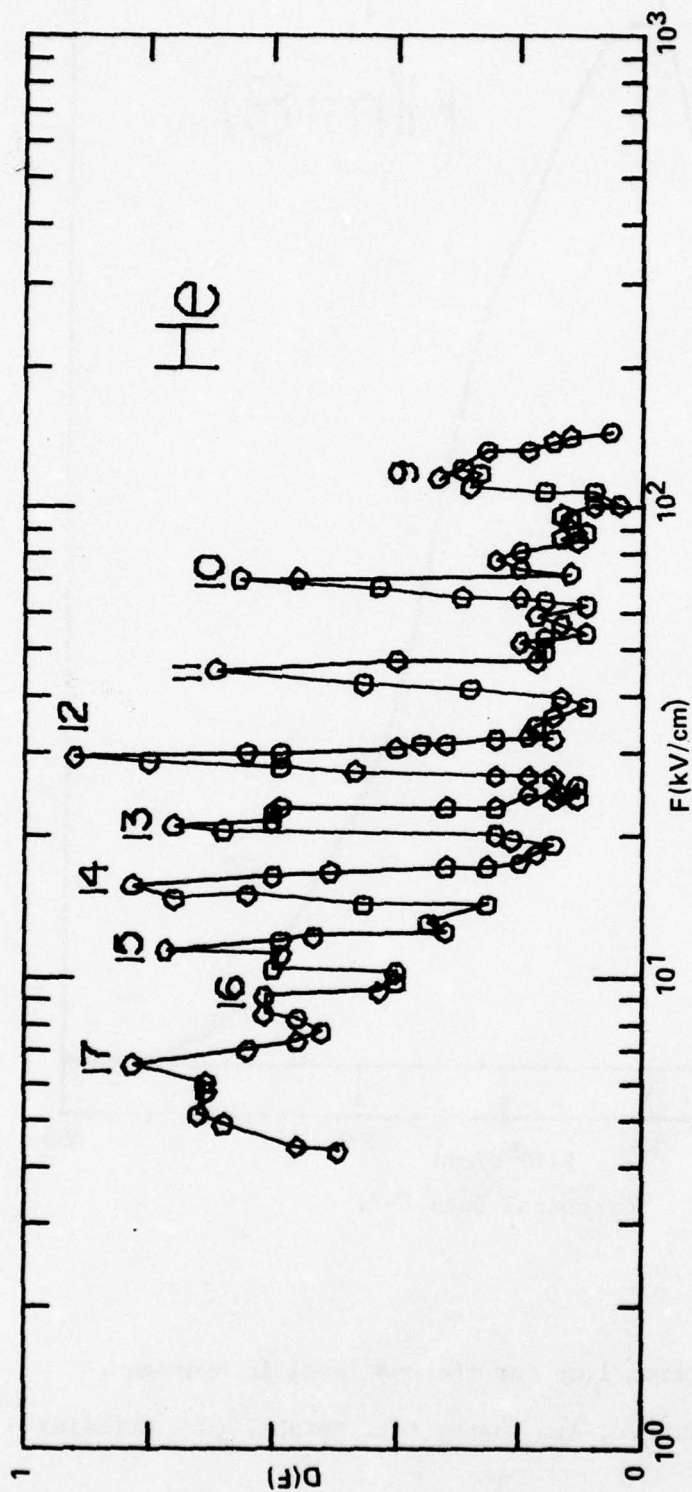
Reference: A. C. Riviere, At. Energy Res. Establ. (Gr. Britain) Report 4818 (1964).



Graphical Data F-7.

Electric field spectrum line for the $n=8$ level in hydrogen.

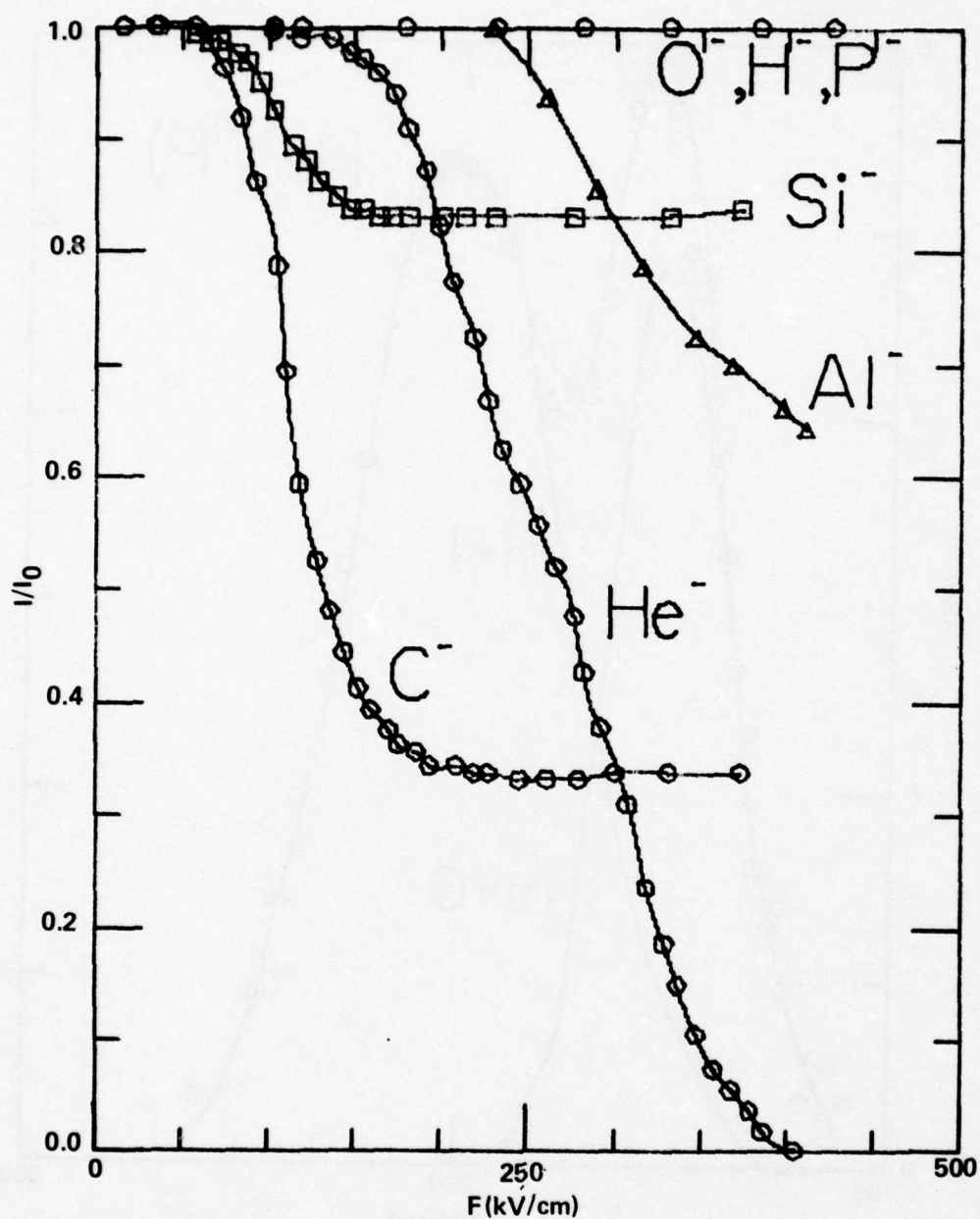
Reference: A. C. Riviere, At. Energy Res. Establ. (Gr. Britain) Report 4818 (1964).



Graphical Data F-8.

Electric field ionization spectrum for helium.

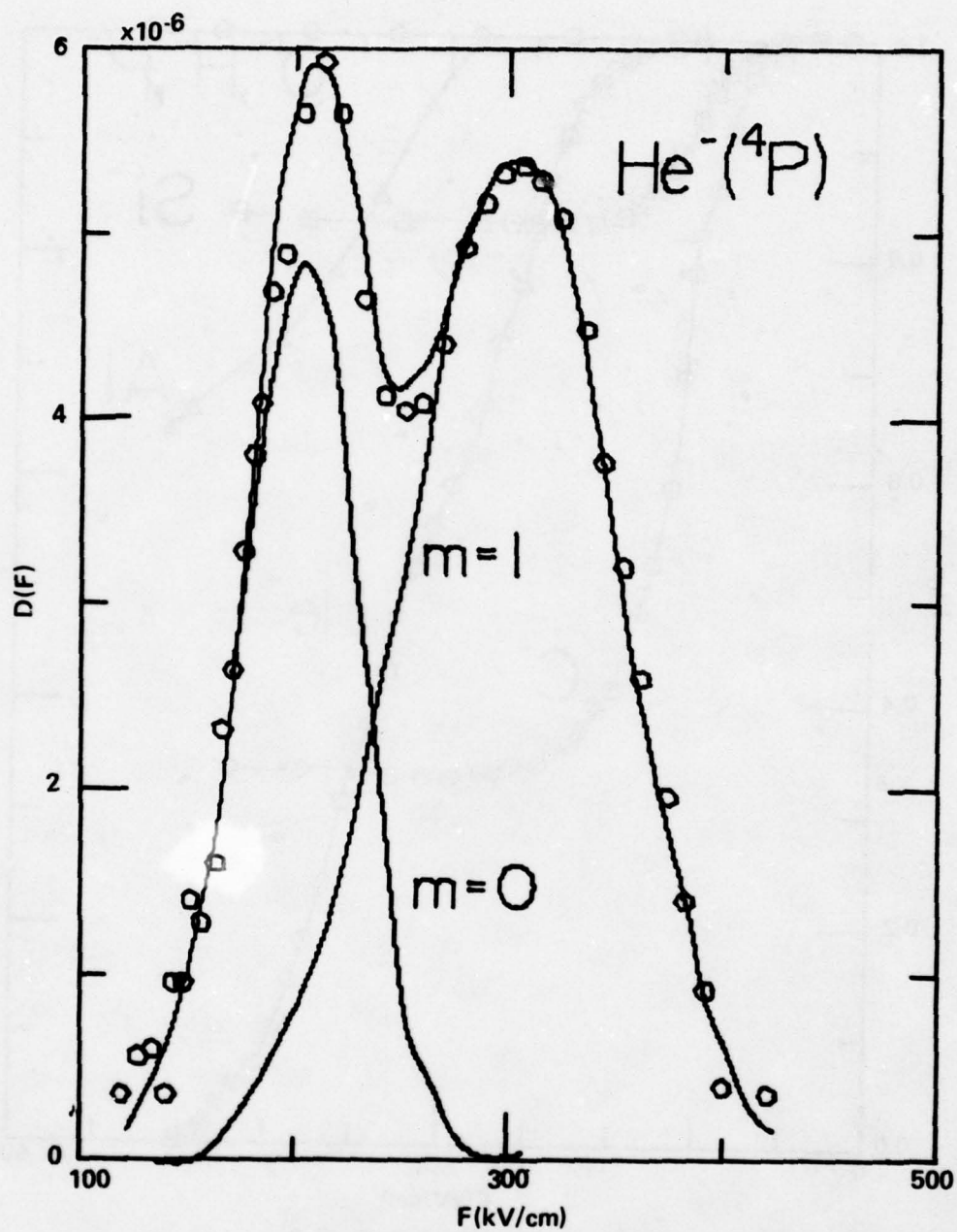
Reference: R. N. Il'in, V. A. Oparin, I. T. Serenkov, E. S. Solov'ev,
N. V. Fedorenko, Zh. Eksperim. i Teor. Fiz. 59, 103 (1970).



Graphical Data F-9.

Beam attenuation in an electric field for different negative ions.

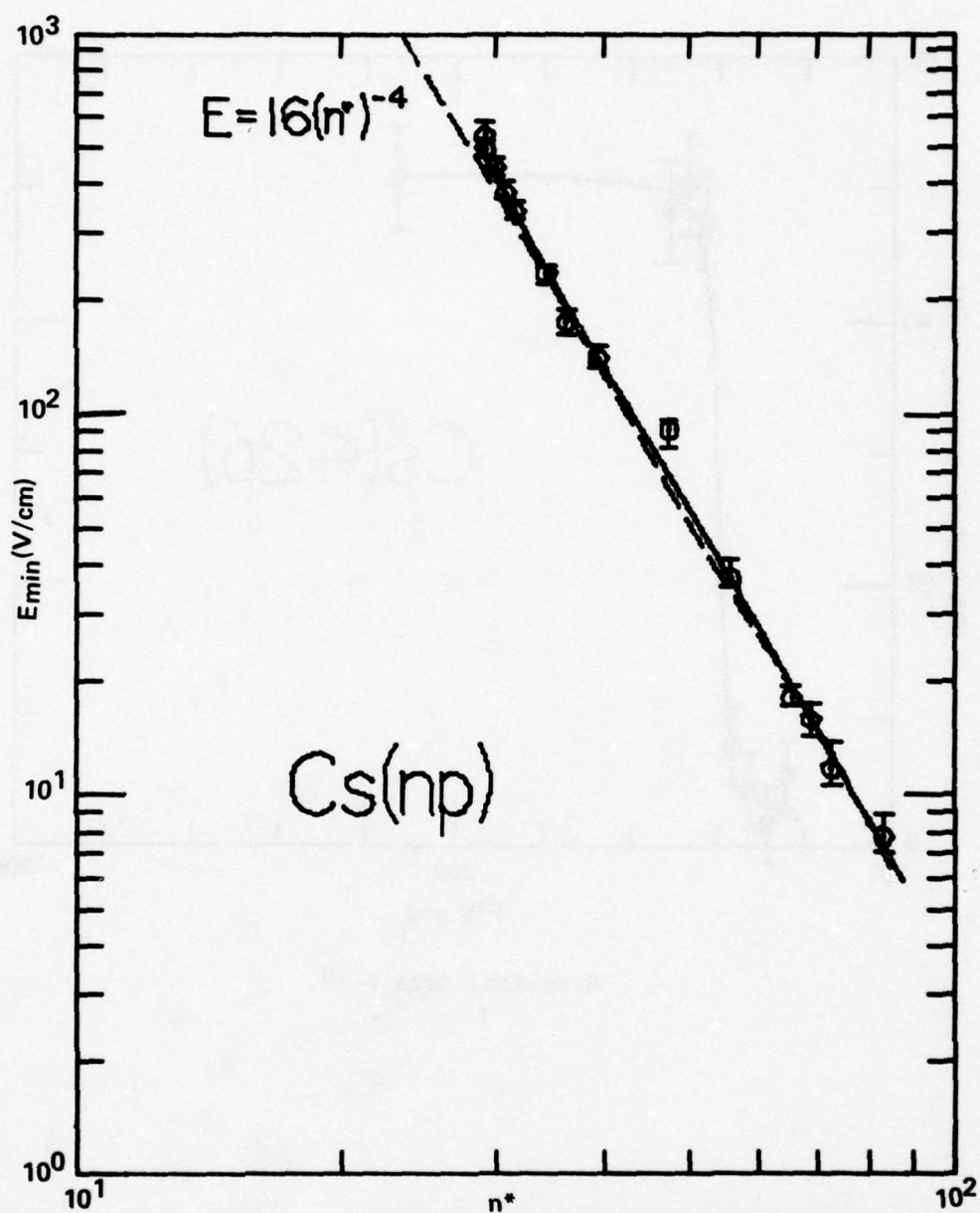
Reference: V. A. Oparin, R. N. Il'in, I. T. Serenkov, E. S. Solov'ev, N. V. Fedorenko, Abstr. of Papers of the 7th Intern. Conf. Phys. Electron. Atomic Collisions, North Holland, Amsterdam, 1971 p. 796.



Graphical Data F-10.

Field ionization spectrum for He^- ions in the $4P$ state.

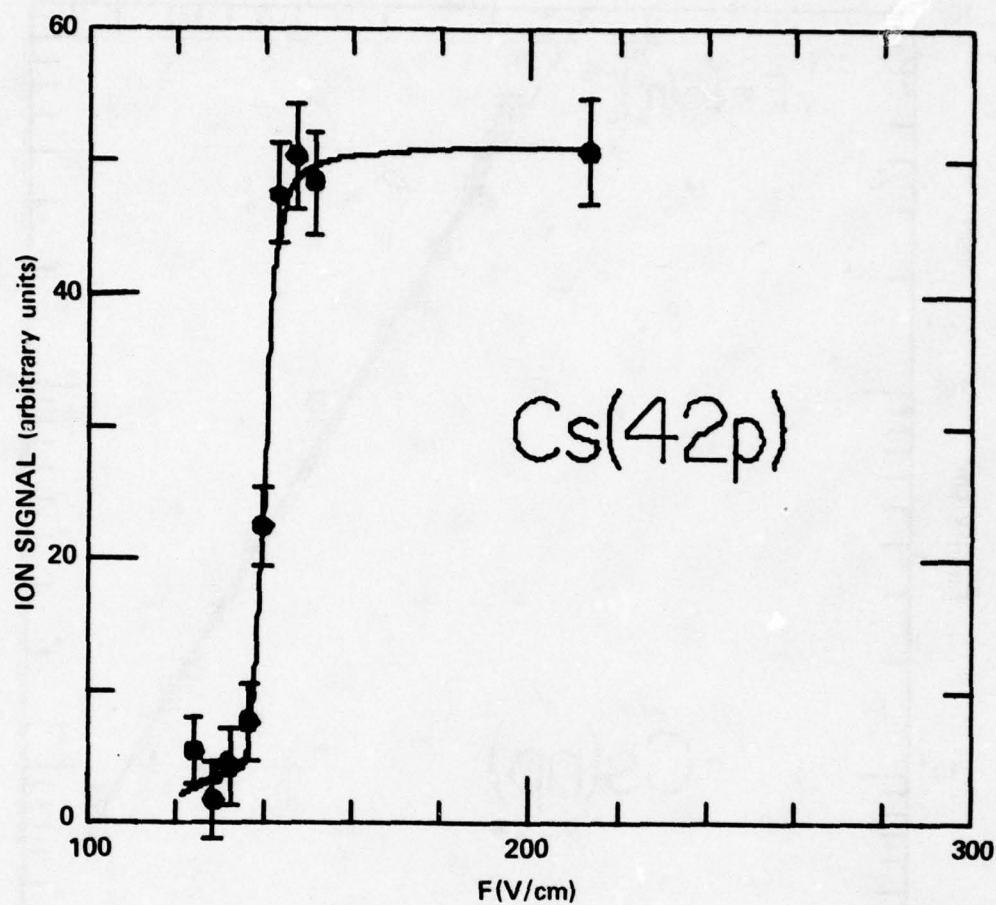
Reference: V. A. Oparin, R. N. Il'in, I. T. Serenkov, E. S. Solov'ev, *Pisma Zh. Eksperim. i Teor. Fiz.* 12, 237 (1970).



Graphical Data F-11.

Minimum electric field strength for field ionization of cesium p states plotted against their effective quantum number n^* . The effective quantum number $n^* = n - \Delta$, where $\Delta = 3.6$ for the p states of cesium, and n is the orbital quantum number.

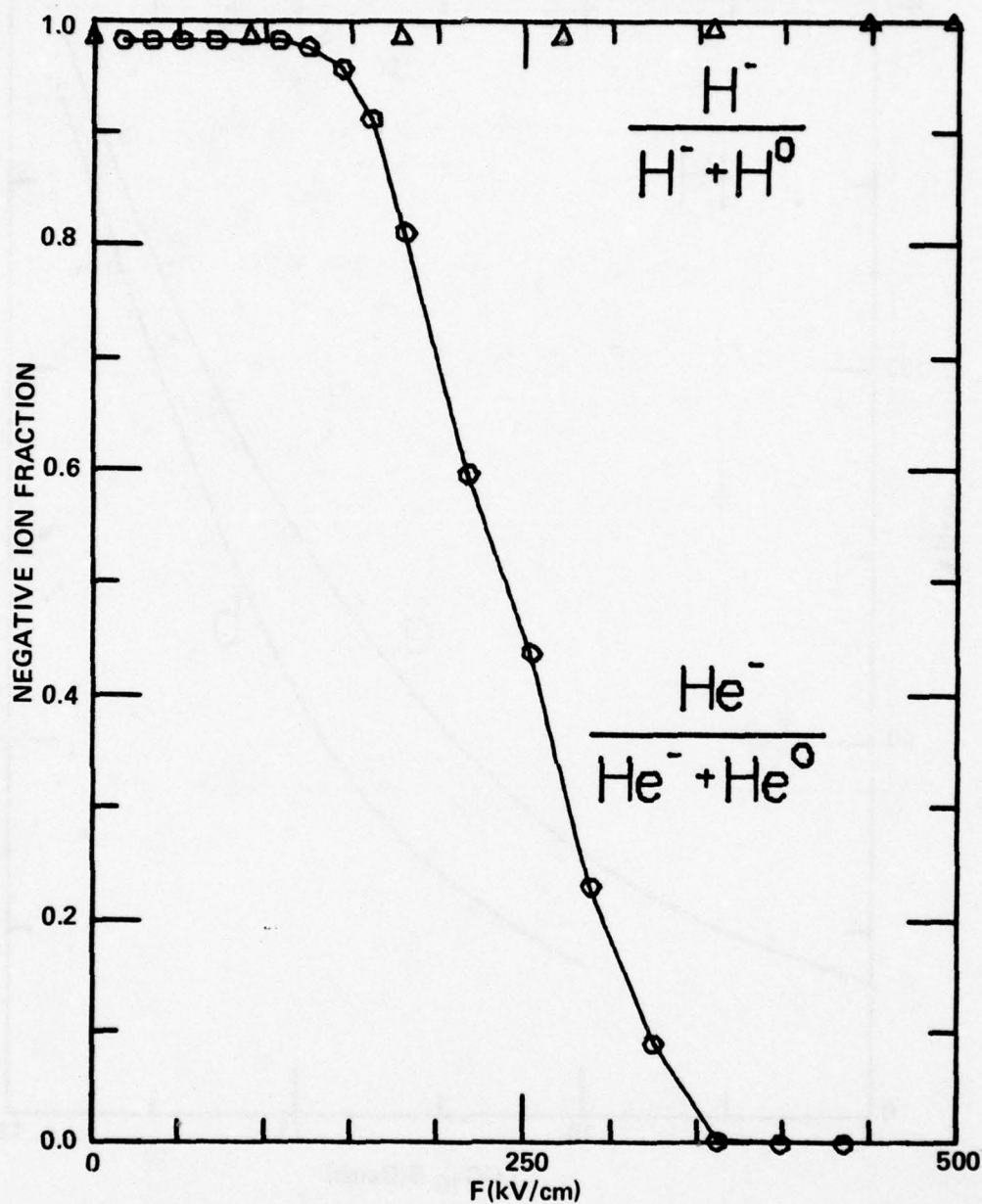
Reference: A. F. J. van Raan, G. Baum, and W. Raith, J. Phys. B: Atom. Molec. Phys. 9, L173 (1976).



Graphical Data F-12.

Ion signal plotted against the electric field strength for field ionization of cesium atoms in the 42p state.

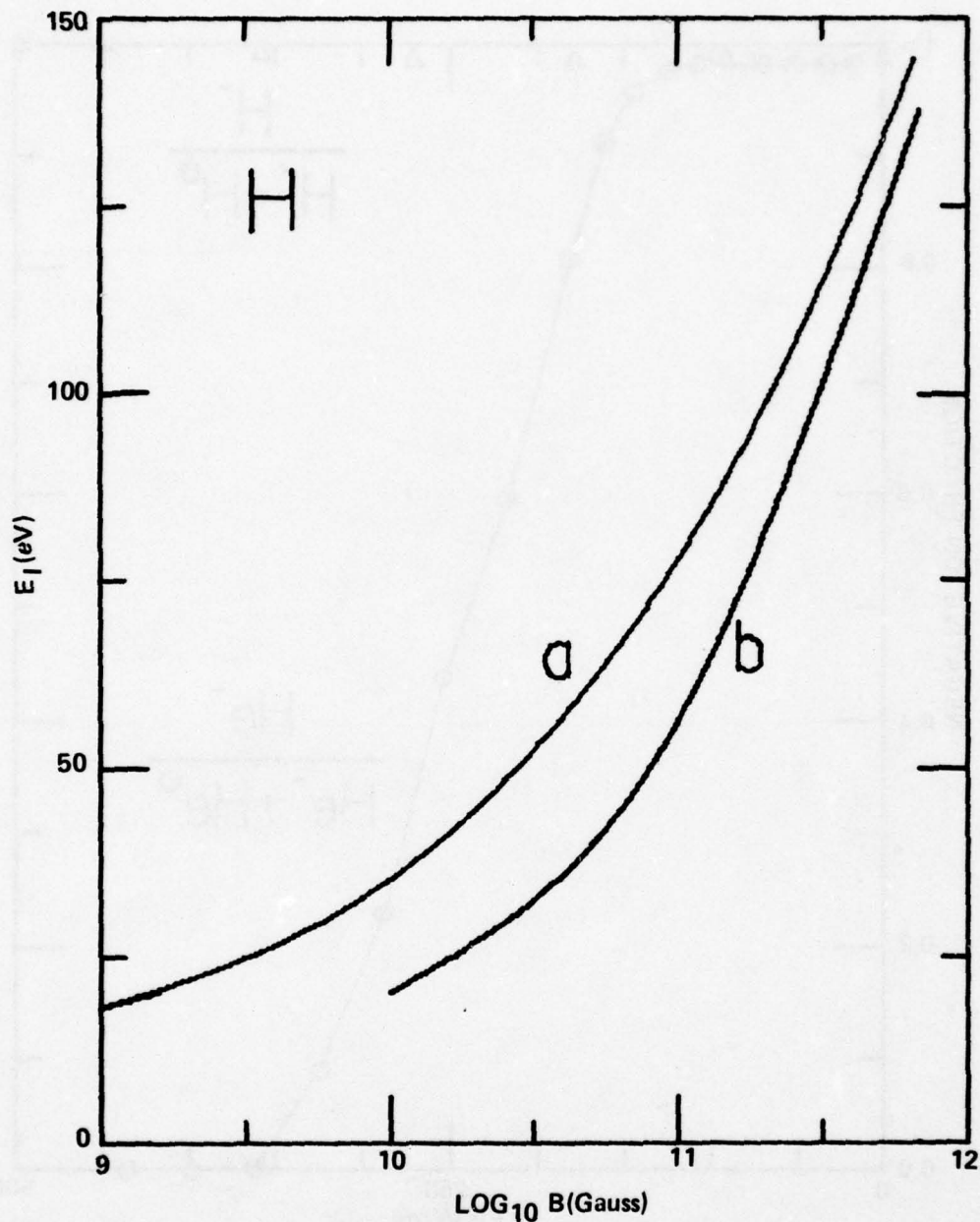
Reference: A. F. J. van Raan, G. Baum, and W. Raith,
J. Phys. B:Atom. Molec. Phys. 9, L173 (1976).



Graphical Data F-13.

Detachment of He^- and H^- as a function of the electric field.

Reference: A. C. Riviere and D. R. Sweetman, Phys. Rev. Lett. 5, 560 (1960).



Graphical Data F-14.

Ionization energy of the ground state of hydrogen as a function of the magnetic field B . The curves all represent theoretical results.

References: (curve a) - E. R. Smith, R. J. W. Henry, G. L. Surmelian, R. F. O'Connell, and A. K. Rajagopal, Phys. Rev. D6, 3700 (1972).

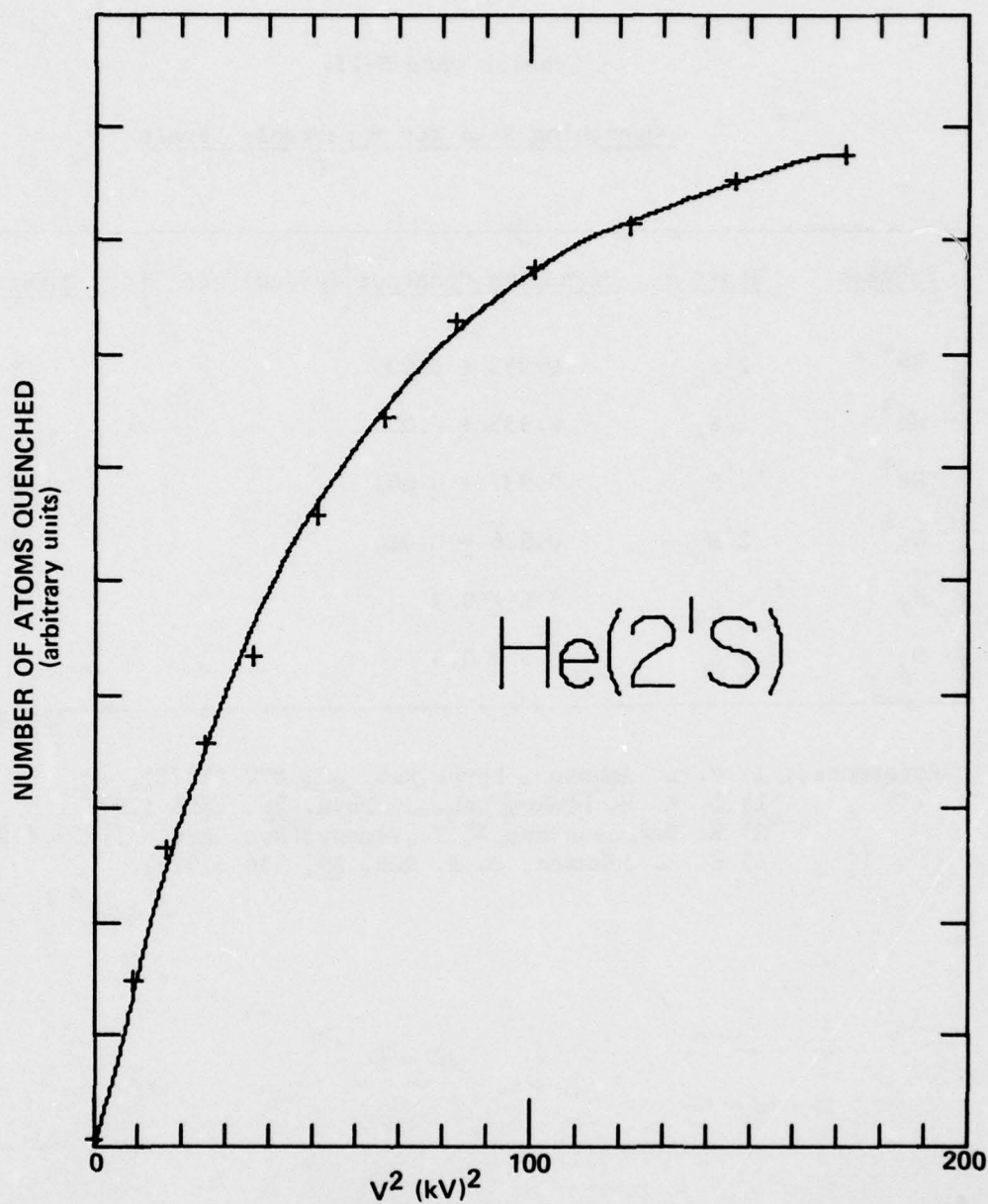
(curve b) - R. Cohen, J. Lodenquai, and M. Ruderman, Phys. Rev. Letters 25, 467 (1970).

Tabular Data F-15.

Quenching Rate for Metastable Levels

<u>Species</u>	<u>State</u>	<u>Quenching Constant</u> $\left\{ (\text{kV/cm})^2 \text{sec}^{-1} \right\}$	<u>Reference</u>
He ⁴	2 ¹ S _o	0.933 ± 0.005	1
He ³	2 ¹ S _o	0.933 ± 0.005	1
He ⁴	2 ¹ S _o	0.932 ± 0.001	2
He ⁴	2 ¹ S _o	0.926 ± 0.020	3
H ₂	c ³ Π _u	8.6 ± 0.3	4
D ₂	c ³ Π _u	8.6 ± 0.3	4

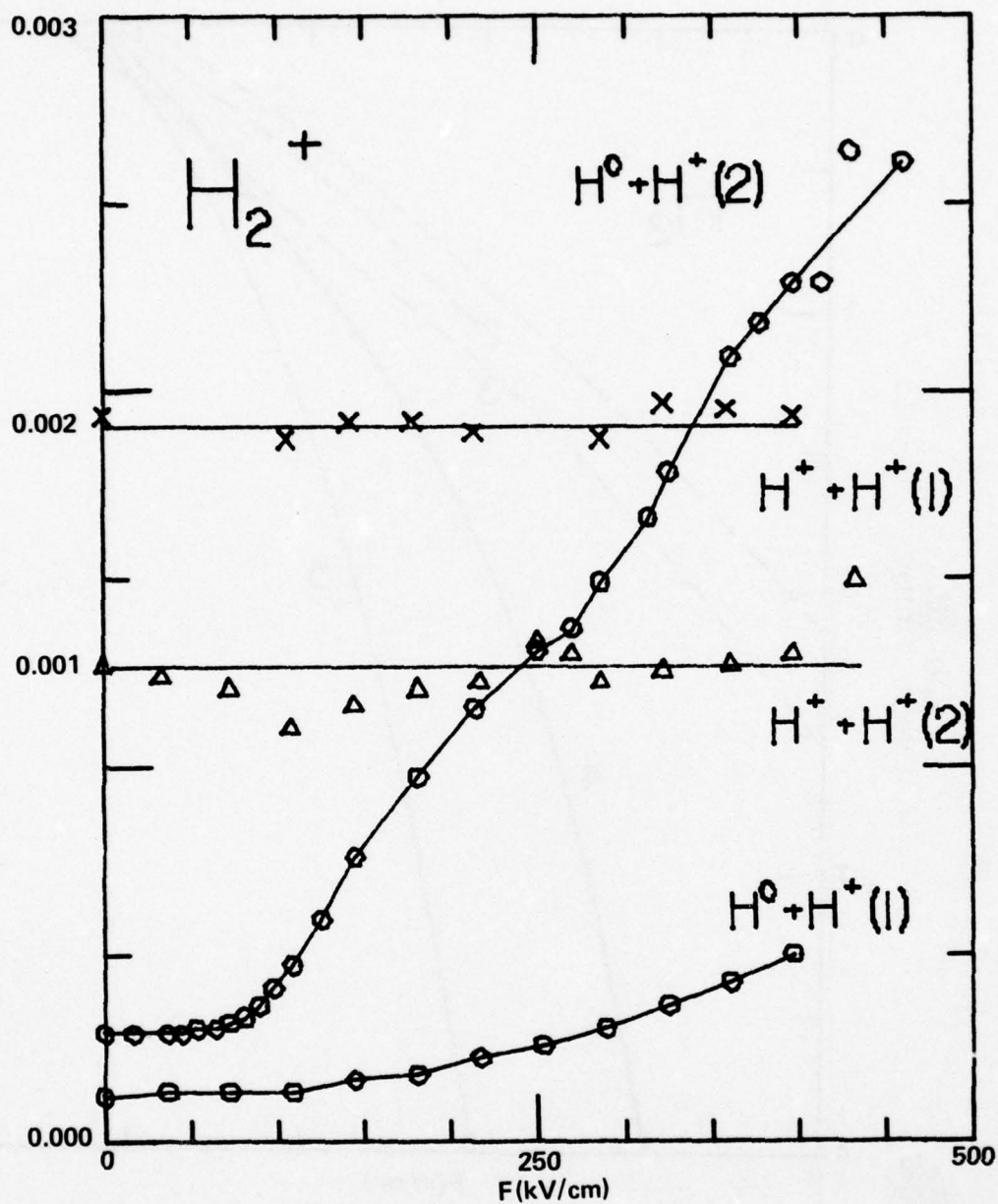
- References: 1) C. E. Johnson, Phys. Rev. A7, 872 (1973).
 2) G. W. F. Drake, Can. J. Phys. 50, 1896 (1972).
 3) R. Petrasso and A. T. Ramsey, Phys. Rev. A5, 79 (1972).
 4) C. E. Johnson, Phys. Rev. A9, 576 (1974).



Graphical Data F-16.

Number of He(2¹S) metastable atoms quenched during transit between two capacitor plates as a function of the square of the potential difference V between the plates.

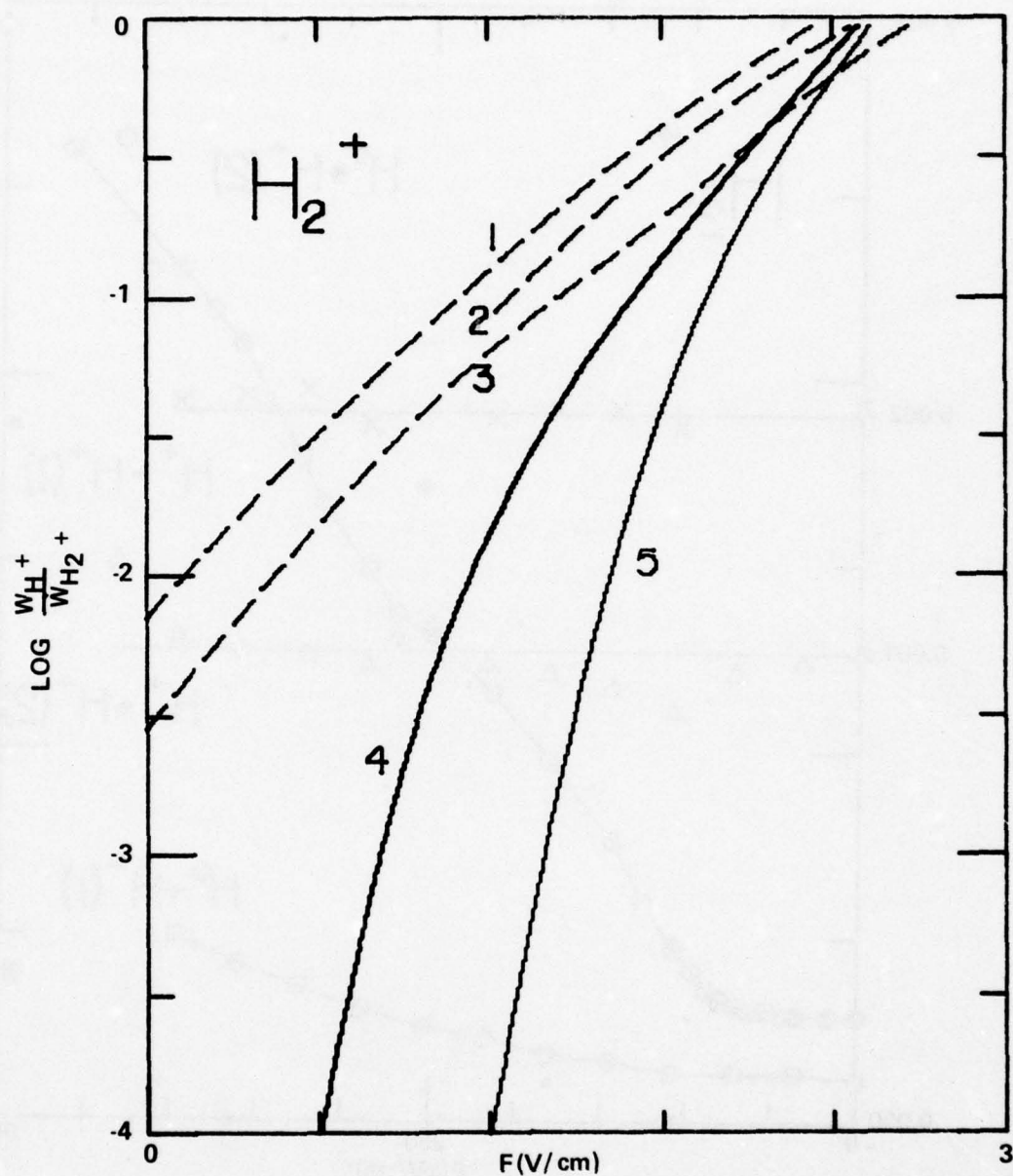
Reference: H. K. Holt and R. Krotkov, Phys. Rev. 144, 82 (1966).



Graphical Data F-17.

Dissociation of H_2^+ ions as a function of the electric field. Curves (1): H_2^+ ions direct from the source. Curves (2): H_2^+ ions from the breakup of H_3^+ ions.

Reference: A. C. Riviere and D. R. Sweetman, Phys. Rev. Lett. 5, 560 (1960).



Graphical Data F-18.

The calculated (curves 1-4) and experimental (curve 5) results for the dissociation of the molecular hydrogen ion.

Reference: E. N. Korol, V. V. Lobanov, and V. A. Pokrovsky, Int. J. Mass Spect. and Ion Phys. 18, 229 (1975).

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G. PARTICLE PENETRATION IN GASES (IONS, NEUTRALS, AND ELECTRONS)

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G-1. ELECTRON ENERGY LOSS AND RANGE

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The following tables are extracted from L. Pages, E. Bertel, H. Joffre, and L. Sklavenitis, "Energy Loss, Range, and Bremsstrahlung Yield for 10 keV to 100 MeV Electrons in Various Elements and Chemical Compounds," Atomic Data, Volume 4, page 1 (1972).

Tabular Data G-1.1.
ELECTRONS IN HELIUM GAS

Energy (MeV)	Energy Loss (MeV·cm ² /gm)			Range (gm/cm ²)	Bremsstrahlung Yield
	by Ionization	by Radiation	Total		
1.0E-02	2.22E 01	1.54E-03	2.22E 01	2.25E-04	3.47E-05
2.0E-02	1.28E 01	1.54E-03	1.28E 01	8.44E-04	6.48E-05
3.0E-02	9.35E 00	1.54E-03	9.35E 00	1.77E-03	9.08E-05
4.0E-02	7.51E 00	1.56E-03	7.51E 00	2.97E-03	1.15E-04
5.0E-02	6.36E 00	1.57E-03	6.36E 00	4.42E-03	1.37E-04
6.0E-02	5.58E 00	1.59E-03	5.58E 00	6.11E-03	1.59E-04
8.0E-02	4.56E 00	1.63E-03	4.57E 00	1.01E-02	1.99E-04
1.0E-01	3.94E 00	1.69E-03	3.94E 00	1.48E-02	2.38E-04
2.0E-01	2.66E 00	2.00E-03	2.66E 00	4.67E-02	4.16E-04
3.0E-01	2.24E 00	2.38E-03	2.24E 00	8.80E-02	5.79E-04
4.0E-01	2.04E 00	2.79E-03	2.04E 00	1.35E-01	7.38E-04
5.0E-01	1.93E 00	3.20E-03	1.93E 00	1.86E-01	8.93E-04
6.0E-01	1.86E 00	3.63E-03	1.86E 00	2.38E-01	1.04E-03
8.0E-01	1.79E 00	4.53E-03	1.80E 00	3.48E-01	1.34E-03
1.0E 00	1.77E 00	5.48E-03	1.77E-00	4.60E-01	1.63E-03
2.0E 00	1.78E 00	1.10E-02	1.79E 00	1.02E 00	3.13E-03
3.0E 00	1.83E 00	1.63E-02	1.85E 00	1.57E 00	4.58E-03
4.0E 00	1.88E 00	2.28E-02	1.91E 00	2.10E 00	6.03E-03
5.0E 00	1.93E 00	2.96E-02	1.96E 00	2.62E 00	7.53E-03
6.0E 00	1.96E 00	3.66E-02	2.00E 00	3.13E 00	9.06E-03
8.0E 00	2.02E 00	5.13E-02	2.08E 00	4.11E 00	1.22E-02
1.0E 01	2.07E 00	6.66E-02	2.14E 00	5.06E 00	1.53E-02
2.0E 01	2.23E 00	1.49E-01	2.38E 00	9.50E 00	3.12E-02
3.0E 01	2.32E 00	2.37E-01	2.56E 00	1.36E 01	4.67E-02
4.0E 01	2.39E 00	3.29E-01	2.71E 00	1.74E 01	6.18E-02
5.0E 01	2.44E 00	4.22E-01	2.86E 00	2.09E 01	7.63E-02
6.0E 01	2.48E 00	5.65E-01	3.04E 00	2.43E 01	9.13E-02
8.0E 01	2.54E 00	7.61E-01	3.31E 00	3.06E 01	1.21E-02
1.0E 02	2.59E 00	9.59E-01	3.55E 00	3.65E 01	1.47E-01

Tabular Data G-1.2.
ELECTRONS IN NEON GAS

Energy (MeV)	Energy Loss (MeV·cm ² /gm)		Range (gm/cm ²)	Yield
	by Ionization	by Radiation		
1.0E-02	1.79E 01	6.73E-03	2.79E-04	1.88E-04
2.0E-02	1.06E 01	6.57E-03	1.03E-03	3.44E-04
3.0E-02	7.82E 00	6.49E-03	2.15E-03	4.72E-04
4.0E-02	6.33E 00	6.50E-03	3.58E-03	5.86E-04
5.0E-02	5.39E 00	6.55E-03	5.29E-03	6.92E-04
6.0E-02	4.74E 00	6.64E-03	7.27E-03	7.94E-04
8.0E-02	3.91E 00	6.86E-03	1.19E-02	9.90E-04
1.0E-01	3.39E 00	7.16E-03	1.74E-02	1.18E-03
2.0E-01	2.32E 00	8.74E-03	5.42E-02	2.06E-03
3.0E-01	1.96E 00	1.05E-02	1.01E-01	2.89E-03
4.0E-01	1.79E 00	1.24E-02	1.55E-01	3.70E-03
5.0E-01	1.70E 00	1.43E-02	2.11E-01	4.48E-03
6.0E-01	1.65E 00	1.62E-02	2.71E-01	5.24E-03
8.0E-01	1.59E 00	1.98E-02	3.93E-01	6.68E-03
1.0E 00	1.57E 00	2.36E-02	5.18E-01	8.05E-03
2.0E 00	1.60E 00	4.33E-02	1.13E 00	1.43E-02
3.0E 00	1.66E 00	6.02E-02	1.73E 00	1.97E-02
4.0E 00	1.71E 00	8.21E-02	2.30E 00	2.49E-02
5.0E 00	1.75E 00	1.05E-01	2.85E 00	3.02E-02
6.0E 00	1.79E 00	1.29E-01	3.38E 00	3.55E-02
8.0E 00	1.85E 00	1.79E-01	4.39E 00	4.60E-02
1.0E 01	1.90E 00	2.30E-01	5.35E 00	5.65E-02
2.0E 01	2.05E 00	5.10E-01	9.65E 00	1.05E-01
3.0E 01	2.14E 00	8.06E-01	1.33E 01	1.49E-01
4.0E 01	2.21E 00	1.11E 00	1.65E 01	1.88E-01
5.0E 01	2.26E 00	1.42E 00	1.94E 01	2.22E-01
6.0E 01	2.30E 00	1.85E 00	2.19E 01	2.54E-01
8.0E 01	2.35E 00	2.50E 00	2.64E 01	3.11E-01
1.0E 02	2.39E 00	3.14E 00	3.02E 01	3.57E-01

Tabular Data G-1.3.
ELECTRONS IN ARGON GAS

Energy (MeV)	Energy Loss (MeV·cm ² /gm)		Total	Range gm/cm ²	Bremsstrahlung Yield
	by Ionization	by Radiation			
1.0E-02	1.46E 01	1.10E-02	1.46E 01	3.43E-04	3.78E-04
2.0E-02	8.77E 00	1.10E-02	8.78E 00	1.26E-03	6.93E-04
3.0E-02	6.52E 00	1.10E-02	6.53E 00	2.60E-03	9.52E-04
4.0E-02	5.30E 00	1.12E-02	5.31E 00	4.31E-03	1.19E-03
5.0E-02	4.53E 00	1.14E-02	4.54E 00	6.35E-03	1.41E-03
6.0E-02	3.99E 00	1.16E-02	4.00E 00	8.71E-03	1.63E-03
8.0E-02	3.30E 00	1.21E-02	3.31E 00	1.42E-02	2.04E-03
1.0E-01	2.87E 00	1.25E-02	2.88E 00	2.07E-02	2.43E-03
2.0E-01	1.97E 00	1.52E-02	1.99E 00	6.38E-02	4.22E-03
3.0E-01	1.68E 00	1.81E-02	1.69E 00	1.19E-01	5.86E-03
4.0E-01	1.54E 00	2.12E-02	1.56E 00	1.81E-01	7.43E-03
5.0E-01	1.46E 00	2.42E-02	1.48E 00	2.46E-01	8.93E-03
6.0E-01	1.42E 00	2.71E-02	1.44E 00	3.15E-01	1.04E-02
8.0E-01	1.37E 00	3.29E-02	1.41E 00	4.56E-01	1.31E-02
1.0E 00	1.36E 00	3.90E-02	1.40E 00	5.98E-01	1.56E-02
2.0E 00	1.39E 00	6.92E-02	1.46E 00	1.30E 00	2.66E-02
3.0E 00	1.44E 00	9.37E-02	1.54E 00	1.97E 00	3.58E-02
4.0E 00	1.49E 00	1.27E-01	1.62E 00	2.60E 00	4.43E-02
5.0E 00	1.53E 00	1.62E-01	1.69E 00	3.21E 00	5.28E-02
6.0E 00	1.56E 00	1.99E-01	1.76E 00	3.78E 00	6.14E-02
8.0E 00	1.62E 00	2.75E-01	1.89E 00	4.88E 00	7.83E-02
1.0E 01	1.66E 00	3.54E-01	2.02E 00	5.90E 00	9.48E-02
2.0E 01	1.80E 00	7.77E-01	2.58E 00	1.03E 01	1.67E-01
3.0E 01	1.89E 00	1.22E 00	3.10E 00	1.39E 01	2.27E-01
4.0E 01	1.94E 00	1.68E 00	3.62E 00	1.69E 01	2.77E-01
5.0E 01	1.98E 00	2.14E 00	4.12E 00	1.95E 01	3.20E-01
6.0E 01	2.01E 00	2.79E 00	4.79E 00	2.17E 01	3.58E-01
8.0E 01	2.05E 00	3.75E 00	5.80E 00	2.55E 01	4.23E-01
1.0E 02	2.09E 00	4.72E 00	6.81E 00	2.87E 01	4.72E-01

Tabular Data G-1.4.

Energy (MeV)	Energy Loss (MeV·cm ² /gm)		Total	Range (gm/cm ²)	Yield
	by Ionization	by Radiation			
1.0E-02	1.18E 01	2.06E-02	1.18E 01	4.23E-04	8.73E-04
2.0E-02	7.29E 00	2.13E-02	7.31E 00	1.54E-03	1.60E-03
3.0E-02	5.48E 00	2.21E-02	5.50E 00	3.13E-03	2.23E-03
4.0E-02	4.48E 00	2.28E-02	4.50E 00	5.15E-03	2.81E-03
5.0E-02	3.85E 00	2.36E-02	3.87E 00	7.56E-03	3.36E-03
6.0E-02	3.41E 00	2.43E-02	3.43E 00	1.03E-02	3.90E-03
8.0E-02	2.83E 00	2.54E-02	2.86E 00	1.67E-02	4.92E-03
1.0E-01	2.47E 00	2.65E-02	2.50E 00	2.43E-02	5.89E-03
2.0E-01	1.72E 00	3.17E-02	1.75E 00	7.36E-02	1.02E-02
3.0E-01	1.47E 00	3.74E-02	1.50E 00	1.36E-01	1.40E-02
4.0E-01	1.35E 00	4.34E-02	1.39E 00	2.05E-01	1.75E-02
5.0E-01	1.29E 00	4.92E-02	1.33E 00	2.79E-01	2.08E-02
6.0E-01	1.25E 00	5.48E-02	1.30E 00	3.55E-01	2.39E-02
8.0E-01	1.22E 00	6.59E-02	1.28E 00	5.10E-01	2.96E-02
1.0E 00	1.21E 00	7.66E-02	1.28E 00	6.66E-01	3.48E-02
2.0E 00	1.24E 00	1.30E-01	1.37E 00	1.42E 00	5.61E-02
3.0E 00	1.30E 00	1.71E-01	1.47E 00	2.12E 00	7.27E-02
4.0E 00	1.34E 00	2.31E-01	1.57E 00	2.78E 00	8.75E-02
5.0E 00	1.38E 00	2.93E-01	1.67E 00	3.40E 00	1.02E-01
6.0E 00	1.41E 00	3.59E-01	1.77E 00	3.98E 00	1.17E-01
8.0E 00	1.46E 00	4.95E-01	1.96E 00	5.06E 00	1.45E-01
1.0E 01	1.50E 00	6.36E-01	2.14E 00	6.03E 00	1.71E-01
2.0E 01	1.64E 00	1.38E 00	3.02E 00	1.00E 01	2.74E-01
3.0E 01	1.72E 00	2.12E 00	3.83E 00	1.30E 01	3.51E-01
4.0E 01	1.77E 00	2.90E 00	4.67E 00	1.54E 01	4.10E-01
5.0E 01	1.81E 00	3.70E 00	5.50E 00	1.73E 01	4.57E-01
6.0E 01	1.84E 00	4.84E 00	6.68E 00	1.90E 01	4.97E-01
8.0E 01	1.89E 00	6.51E 00	8.40E 00	2.17E 01	5.61E-01
1.0E 02	1.92E 00	8.21E 00	1.01E 01	2.38E 01	6.07E-01

Tabular Data G-1.5.
ELECTRONS IN XENON GAS

Energy (MeV)	Energy Loss (MeV·cm ² /gm)		Total	Range (gm/cm ²)	Bremsstrahlung Yield
	by Ionization	by Radiation			
1.0E-02	1.01E 01	2.90E-02	1.01E 01	4.95E-04	1.44E-03
2.0E-02	6.34E 00	3.05E-02	6.37E 00	1.78E-03	2.64E-03
3.0E-02	4.81E 00	3.20E-02	4.84E 00	3.61E-03	3.66E-03
4.0E-02	3.95E 00	3.36E-02	3.99E 00	5.90E-03	4.63E-03
5.0E-02	3.41E 00	3.47E-02	3.44E 00	8.60E-03	5.55E-03
6.0E-02	3.02E 00	3.58E-02	3.06E 00	1.17E-02	6.45E-03
8.0E-02	2.52E 00	3.76E-02	2.56E 00	1.89E-02	8.14E-03
1.0E-01	2.21E 00	3.94E-02	2.25E 00	2.73E-02	9.73E-03
2.0E-01	1.55E 00	4.72E-02	1.59E 00	8.17E-02	1.67E-02
3.0E-01	1.32E 00	5.56E-02	1.38E 00	1.50E-01	2.28E-02
4.0E-01	1.22E 00	6.44E-02	1.29E 00	2.25E-01	2.84E-02
5.0E-01	1.17E 00	7.26E-02	1.24E 00	3.04E-01	3.36E-02
6.0E-01	1.14E 00	8.06E-02	1.22E 00	3.86E-01	3.84E-02
8.0E-01	1.11E 00	9.65E-02	1.20E 00	5.51E-01	4.71E-02
1.0E-00	1.10E 00	1.11E-01	1.21E 00	7.17E-01	5.49E-02
2.0E 00	1.14E 00	1.85E-01	1.33E 00	1.51E 00	8.53E-02
3.0E 00	1.19E 00	2.38E-01	1.43E 00	2.23E 00	1.08E-01
4.0E 00	1.24E 00	3.19E-01	1.55E 00	2.90E 00	1.27E-01
5.0E 00	1.27E 00	4.05E-01	1.68E 00	3.52E 00	1.47E-01
6.0E 00	1.30E 00	4.94E-01	1.80E 00	4.10E 00	1.65E-01
8.0E 00	1.35E 00	6.79E-01	2.03E 00	5.15E 00	2.00E-01
1.0E 01	1.39E 00	8.70E-01	2.26E 00	6.08E 00	2.32E-01
2.0E 01	1.52E 00	1.87E-00	3.39E 00	9.70E 00	3.50E-01
3.0E 01	1.59E 00	2.79E 00	4.38E 00	1.24E 01	4.31E-01
4.0E 01	1.64E 00	3.80E 00	5.44E 00	1.44E 01	4.90E-01
5.0E 01	1.68E 00	4.83E 00	6.51E 00	1.61E 01	5.36E-01
6.0E 01	1.71E 00	6.43E 00	8.14E 00	1.75E 01	5.75E-01
8.0E 01	1.76E 00	8.66E 00	1.04E 01	1.97E 01	6.34E-01
1.0E 02	1.79E 00	1.09E 01	1.27E 01	2.14E 01	6.76E-01

Tabular Data G-1.6.
ELECTRONS IN ATOMIC FLUORINE GAS

Energy (MeV)	Energy Loss (MeV·cm ² /gm)		Total	Range (gm/cm ²)	Bremsstrahlung Yield
	by Ionization	by Radiation			
1.0E-02	1.75E 01	5.78E-03	1.76E 01	2.85E-04	1.65E-04
2.0E-02	1.04E 01	5.64E-03	1.04E 01	1.06E-03	3.02E-04
3.0E-02	7.63E 00	5.57E-03	7.64E 00	2.20E-03	4.14E-04
4.0E-02	6.17E 00	5.57E-03	6.18E 00	3.66E-03	5.14E-04
5.0E-02	5.25E 00	5.60E-03	5.26E 00	5.42E-03	6.08E-04
6.0E-02	4.62E 00	5.67E-03	4.63E 00	7.46E-03	6.98E-04
8.0E-02	3.80E 00	5.87E-03	3.81E 00	1.23E-03	8.70E-04
1.0E-01	3.30E 00	6.11E-03	3.30E 00	1.79E-02	1.04E-03
2.0E-01	2.25E 00	7.47E-03	2.26E 00	5.57E-02	1.81E-03
3.0E-01	1.90E 00	9.01E-03	1.91E 00	1.04E-01	2.55E-03
4.0E-01	1.74E 00	1.07E-02	1.75E 00	1.59E-01	3.26E-03
5.0E-01	1.65E 00	1.23E-02	1.66E 00	2.18E-01	3.96E-03
6.0E-01	1.60E 00	1.39E-02	1.61E 00	2.79E-01	4.64E-03
8.0E-01	1.54E 00	1.70E-02	1.56E 00	4.06E-01	5.92E-03
1.0E 00	1.52E 00	2.03E-02	1.54E 00	5.35E-01	7.14E-03
2.0E 00	1.55E 00	3.74E-02	1.59E 00	1.17E 00	1.28E-02
3.0E 00	1.60E 00	5.24E-02	1.66E 00	1.79E 00	1.77E-02
4.0E 00	1.65E 00	7.15E-02	1.72E 00	2.38E 00	2.24E-02
5.0E 00	1.69E 00	9.17E-02	1.78E 00	2.95E 00	2.72E-02
6.0E 00	1.73E 00	1.13E-01	1.84E 00	3.50E 00	3.21E-02
8.0E 00	1.79E 00	1.56E-01	1.94E 00	4.56E 00	4.17E-02
1.0E 01	1.83E 00	2.01E-01	2.03E 00	5.57E 00	5.13E-02
2.0E 01	1.98E 00	4.46E-01	2.42E 00	1.01E 01	9.63E-02
3.0E 01	2.07E 00	7.04E-01	2.77E 00	1.40E 01	1.37E-01
4.0E 01	2.12E 00	9.71E-01	3.09E 00	1.74E 01	1.74E-01
5.0E 01	2.16E 00	1.24E 00	3.40E 00	2.05E 01	2.07E-01
6.0E 01	2.19E 00	1.62E 00	3.81E 00	2.32E 01	2.38E-01
8.0E 01	2.23E 00	2.19E 00	4.42E 00	2.81E 01	2.94E-01
1.0E 02	2.26E 00	2.75E 00	5.01E 00	3.24E 01	3.40E-01

Tabular Data G-1.7.
ELECTRONS IN ATOMIC CHLORINE

Energy (MeV)	Energy Loss (MeV·cm ² /gm)			Range ₂ (gm/cm ²)	Bremsstrahlung Yield
	by Ionization	by Radiation	Total		
1.0E-02	1.57E 01	1.11E-02	1.57E 01	3.19E-04	3.53E-04
2.0E-02	9.42E 00	1.10E-02	9.43E 00	1.17E-03	6.48E-04
3.0E-02	7.00E 00	1.10E-02	7.01E 00	2.42E-03	8.90E-04
4.0E-02	5.68E 00	1.12E-02	5.69E 00	4.01E-03	1.11E-03
5.0E-02	4.85E 00	1.13E-02	4.87E 00	5.92E-03	1.32E-03
6.0E-02	4.28E 00	1.16E-02	4.29E 00	8.11E-03	1.52E-03
8.0E-02	3.54E 00	1.20E-02	3.55E 00	1.33E-02	1.90E-03
1.0E-01	3.07E 00	1.25E-02	3.09E 00	1.93E-02	2.26E-03
2.0E-01	2.11E 00	1.51E-02	2.13E 00	5.96E-02	3.93E-03
3.0E-01	1.79E 00	1.80E-02	1.81E 00	1.11E-01	5.47E-03
4.0E-01	1.64E 00	2.12E-02	1.67E 00	1.69E-01	6.94E-03
5.0E-01	1.56E 00	2.42E-02	1.59E 00	2.30E-01	8.35E-03
6.0E-01	1.51E 00	2.72E-02	1.54E 00	2.94E-01	9.70E-03
8.0E-01	1.47E 00	3.31E-02	1.50E 00	4.26E-01	1.22E-02
1.0E 00	1.45E 00	3.91E-02	1.49E 00	5.60E-01	1.46E-02
2.0E 00	1.49E 00	6.97E-02	1.56E 00	1.22E 00	2.50E-02
3.0E 00	1.54E 00	9.45E-02	1.64E 00	1.84E 00	3.38E-02
4.0E 00	1.59E 00	1.28E-01	1.72E 00	2.44E 00	4.19E-02
5.0E 00	1.63E 00	1.64E-01	1.80E 00	3.01E 00	5.00E-02
6.0E 00	1.67E 00	2.01E-01	1.87E 00	3.55E 00	5.82E-02
8.0E 00	1.73E 00	2.78E-01	2.01E 00	4.58E 00	7.44E-02
1.0E 01	1.78E 00	3.57E-01	2.13E 00	5.55E 00	9.02E-02
2.0E 01	1.92E 00	7.87E-01	2.71E 00	9.74E 00	1.60E-01
3.0E 01	2.00E 00	1.23E 00	3.23E 00	1.31E 01	2.19E-01
4.0E 01	2.05E 00	1.70E 00	3.74E 00	1.60E 01	2.68E-01
5.0E 01	2.08E 00	2.17E 00	4.25E 00	1.85E 01	3.11E-01
6.0E 01	2.11E 00	2.82E 00	4.93E 00	2.07E 01	3.49E-01
8.0E 01	2.16E 00	3.80E 00	5.96E 00	2.44E 01	4.13E-01
1.0E 02	2.20E 00	4.78E 00	6.98E 00	2.75E 01	4.63E-01

Tabular Data G-1.8.
ELECTRONS IN ATOMIC BROMINE

Energy (MeV)	Energy Loss (MeV·cm ² /gm)		Range ₂ (gm/cm ²)	Bremsstrahlung Yield
	by Ionization	by Radiation		
1.0E-02	1.21E 01	2.05E-02	1.22E 01	8.42E-04
2.0E-02	7.48E 00	2.11E-02	7.50E 00	1.55E-03
3.0E-02	5.62E 00	2.18E-02	5.64E 00	2.15E-03
4.0E-02	4.60E 00	2.26E-02	4.62E 00	2.71E-03
5.0E-02	3.94E 00	2.33E-02	3.97E 00	3.24E-03
6.0E-02	3.49E 00	2.40E-02	3.51E 00	3.76E-03
8.0E-02	2.90E 00	2.51E-02	2.92E 00	4.75E-03
1.0E-01	2.53E 00	2.61E-02	2.56E 00	5.68E-03
2.0E-01	1.76E 00	3.13E-02	1.79E 00	9.81E-03
3.0E-01	1.50E 00	3.69E-02	1.54E 00	1.35E-02
4.0E-01	1.38E 00	4.29E-02	1.42E 00	1.69E-02
5.0E-01	1.32E 00	4.86E-02	1.36E 00	2.01E-02
6.0E-01	1.28E 00	5.41E-02	1.33E 00	2.31E-02
8.0E-01	1.24E 00	6.51E-02	1.31E 00	2.86E-02
1.0E 00	1.23E 00	7.59E-02	1.31E 00	3.37E-02
2.0E 00	1.27E 00	1.29E-01	1.40E 00	5.44E-02
3.0E 00	1.32E 00	1.70E-01	1.49E 00	7.06E-02
4.0E 00	1.37E 00	2.29E-01	1.60E 00	8.51E-02
5.0E 00	1.41E 00	2.91E-01	1.70E 00	9.95E-02
6.0E 00	1.44E 00	3.56E-01	1.80E 00	1.14E-01
8.0E 00	1.50E 00	4.92E-01	1.99E 00	1.41E-01
1.0E 01	1.54E 00	6.32E-01	2.17E 00	1.67E-01
2.0E 01	1.67E 00	1.37E 00	3.04E 00	2.69E-01
3.0E 01	1.74E 00	2.11E 00	3.85E 00	3.46E-01
4.0E 01	1.79E 00	2.89E 00	4.69E 00	4.05E-01
5.0E 01	1.83E 00	3.68E 00	5.51E 00	4.52E-01
6.0E 01	1.86E 00	4.81E 00	6.68E 00	4.93E-01
8.0E 01	1.91E 00	6.48E 00	8.39E 00	5.57E-01
1.0E 02	1.94E 00	8.17E 00	1.01E 01	6.03E-01

Tabular Data G-1.9.

ELECTRONS IN ATOMIC IODINE

Energy (MeV)	Energy Loss (MeV·cm ² /gm)		Total	Range (gm/cm ²)	Bremsstrahlung Yield
	by Ionization	by Radiation			
1.0E-02	1.03E 01	2.83E-02	1.03E 01	4.85E-04	1.37E-03
2.0E-02	6.47E 00	2.98E-02	6.50E 00	1.75E-03	2.52E-03
3.0E-02	4.90E 00	3.12E-02	4.93E 00	3.53E-03	3.50E-03
4.0E-02	4.03E 00	3.27E-02	4.06E 00	5.78E-03	4.42E-03
5.0E-02	3.47E 00	3.38E-02	3.51E 00	8.44E-03	5.31E-03
6.0E-02	3.08E 00	3.48E-02	3.12E 00	1.15E-02	6.16E-03
8.0E-02	2.57E 00	3.66E-02	2.61E 00	1.85E-02	7.77E-03
1.0E-01	2.25E 00	3.83E-02	2.29E 00	2.68E-02	9.30E-03
2.0E-01	1.57E 00	4.59E-02	1.62E 00	8.02E-02	1.60E-02
3.0E-01	1.35E 00	5.41E-02	1.40E 00	1.47E-01	2.18E-02
4.0E-01	1.24E 00	6.26E-02	1.30E 00	2.21E-01	2.72E-02
5.0E-01	1.18E 00	7.07E-02	1.25E 00	3.00E-01	3.22E-02
6.0E-01	1.15E 00	7.85E-02	1.23E 00	3.80E-01	3.69E-02
8.0E-01	1.12E 00	9.41E-02	1.21E 00	5.44E-01	4.53E-02
1.0E-00	1.11E 00	1.08E-01	1.22E 00	7.09E-01	5.30E-02
2.0E 00	1.14E 00	1.81E-01	1.32E 00	1.50E 00	8.30E-02
3.0E 00	1.18E 00	2.32E-01	1.41E 00	2.23E 00	1.06E-01
4.0E 00	1.21E 00	3.12E-01	1.52E 00	2.92E 00	1.25E-01
5.0E 00	1.24E 00	3.95E-01	1.63E 00	3.55E 00	1.45E-01
6.0E 00	1.26E 00	4.82E-01	1.74E 00	4.15E 00	1.64E-01
8.0E 00	1.30E 00	6.63E-01	1.96E 00	5.23E 00	2.00E-01
1.0E 01	1.32E 00	8.50E-01	2.17E 00	6.20E 00	2.33E-01
2.0E 01	1.41E 00	1.83E 00	3.23E 00	1.00E 01	3.56E-01
3.0E 01	1.45E 00	2.73E 00	4.18E 00	1.28E 01	4.40E-01
4.0E 01	1.48E 00	3.72E 00	5.20E 00	1.49E 01	5.01E-01
5.0E 01	1.50E 00	4.73E 00	6.22E 00	1.67E 01	5.49E-01
6.0E 01	1.51E 00	6.29E 00	7.80E 00	1.82E 01	5.88E-01
8.0E 01	1.54E 00	8.47E 00	1.00E 01	2.04E 01	6.48E-01
1.0E 02	1.56E 00	1.07E 01	1.22E 01	2.22E 01	6.90E-01

Tabular Data G-1.10.
ELECTRONS IN ATOMIC HYDROGEN GAS

Energy (MeV)	Energy Loss (MeV·cm ² /gm)			Range (gm/cm ²)	Bremsstrahlung Yield
	by Ionization	by Radiation	Total		
1.0E-02	5.14E 01	1.96E-03	5.14E 01	9.72E-05	1.90E-05
2.0E-02	2.93E 01	1.97E-03	2.93E 01	3.67E-04	3.60E-05
3.0E-02	2.12E 01	1.99E-03	2.12E 01	7.75E-04	5.10E-05
4.0E-02	1.69E 01	2.02E-03	1.69E 01	1.31E-03	6.50E-05
5.0E-02	1.43E 01	2.04E-03	1.43E 01	1.95E-03	7.82E-05
6.0E-02	1.25E 01	2.07E-03	1.25E 01	2.70E-03	9.10E-05
8.0E-02	1.02E 01	2.13E-03	1.02E 01	4.49E-03	1.15E-04
1.0E-01	8.76E 00	2.19E-03	8.76E 00	6.62E-03	1.38E-04
2.0E-01	5.86E 00	2.53E-03	5.87E 00	2.10E-02	2.40E-04
3.0E-01	4.91E 00	2.92E-03	4.91E 00	3.99E-02	3.31E-04
4.0E-01	4.45E 00	3.37E-03	4.46E 00	6.13E-02	4.17E-04
5.0E-01	4.20E 00	3.85E-03	4.21E 00	8.45E-02	5.01E-04
6.0E-01	4.05E 00	4.37E-03	4.05E 00	1.09E-01	5.83E-04
8.0E-01	3.89E 00	5.50E-03	3.90E 00	1.59E-01	7.48E-04
1.0E 00	3.82E 00	6.73E-03	3.83E 00	2.11E-01	9.16E-04
2.0E 00	3.83E 00	1.40E-02	3.84E 00	4.72E-01	1.81E-03
3.0E 00	3.93E 00	2.14E-02	3.95E 00	7.28E-01	2.71E-03
4.0E 00	4.03E 00	3.01E-02	4.06E 00	9.78E-01	3.64E-03
5.0E 00	4.11E 00	3.92E-02	4.15E 00	1.22E 00	4.60E-03
6.0E 00	4.18E 00	4.88E-02	4.23E 00	1.46E 00	5.58E-03
8.0E 00	4.30E 00	6.87E-02	4.37E 00	1.93E 00	7.59E-03
1.0E 01	4.40E 00	8.96E-02	4.49E 00	2.38E 00	9.64E-03
2.0E 01	4.70E 00	2.02E-01	4.90E 00	4.51E 00	2.01E-02
3.0E 01	4.89E 00	3.22E-01	5.21E 00	6.49E 00	3.06E-02
4.0E 01	5.01E 00	4.46E-01	5.46E 00	8.37E 00	4.09E-02
5.0E 01	5.09E 00	5.74E-01	5.66E 00	1.02E 01	5.10E-02
6.0E 01	5.14E 00	7.79E-01	5.92E 00	1.19E 01	6.19E-02
8.0E 01	5.20E 00	1.05E 00	6.25E 00	1.52E 01	8.39E-02
1.0E 02	5.25E 00	1.32E 00	6.57E 00	1.83E 01	1.04E-01

Tabular Data C-1.11.
ELECTRONS IN ATOMIC NITROGEN GAS

Energy (MeV)	Energy Loss (MeV·cm ² /gm)		Range (gm/cm ²)	Bremstrahlung Yield
	by Ionization	by Radiation		
1.0E-02	1.98E 01	4.73E-03	1.98E 01	1.20E-04
2.0E-02	1.16E 01	4.61E-03	1.16E 01	2.20E-04
3.0E-02	8.51E 00	4.56E-03	8.51E 00	3.02E-04
4.0E-02	6.86E 00	4.55E-03	6.87E 00	3.77E-04
5.0E-02	5.83E 00	4.57E-03	5.83E 00	4.46E-04
6.0E-02	5.12E 00	4.62E-03	5.12E 00	5.12E-04
8.0E-02	4.20E 00	4.78E-03	4.21E 00	6.39E-04
1.0E-01	3.64E 00	4.97E-03	3.64E 00	7.61E-04
2.0E-01	2.47E 00	6.08E-03	2.48E 00	1.34E-03
3.0E-01	2.09E 00	7.35E-03	2.09E 00	1.88E-03
4.0E-01	1.90E 00	8.72E-03	1.91E 00	2.42E-03
5.0E-01	1.80E 00	1.01E-02	1.81E 00	2.95E-03
6.0E-01	1.75E 00	1.14E-02	1.76E 00	3.46E-03
8.0E-01	1.69E 00	1.40E-02	1.70E 00	4.43E-03
1.0E 00	1.66E 00	1.68E-02	1.68E 00	5.36E-03
2.0E 00	1.69E 00	3.12E-02	1.72E 00	9.71E-03
3.0E 00	1.74E 00	4.42E-02	1.79E 00	1.36E-02
4.0E 00	1.79E 00	6.06E-02	1.85E 00	1.74E-02
5.0E 00	1.84E 00	7.79E-02	1.91E 00	2.13E-02
6.0E 00	1.87E 00	9.58E-02	1.97E 00	2.52E-02
8.0E 00	1.93E 00	1.33E-01	2.07E 00	3.30E-02
1.0E 01	1.98E 00	1.71E-01	2.15E 00	4.08E-02
2.0E 01	2.14E 00	3.80E-01	2.52E 00	7.80E-02
3.0E 01	2.22E 00	6.02E-01	2.82E 00	1.13E-01
4.0E 01	2.27E 00	8.30E-01	3.10E 00	1.45E-01
5.0E 01	2.31E 00	1.06E 00	3.37E 00	1.74E-01
6.0E 01	2.33E 00	1.39E 00	3.73E 00	2.02E-01
8.0E 01	2.37E 00	1.88E 00	4.25E 00	2.54E-01
1.0E 02	2.40E 00	2.36E 00	4.77E 00	2.97E-01

Tabular Data G-1.12.
ELECTRONS IN ATOMIC OXYGEN GAS

Energy (MeV)	Energy Loss (MeV·cm ² /gm)		Range (gm/cm ²)	Yield
	by Ionization	by Radiation		
1.0E-02	1.96E 01	5.42E-03	2.55E-04	1.38E-04
2.0E-02	1.15E 01	5.28E-03	9.47E-04	2.54E-04
3.0E-02	8.45E 00	5.21E-03	1.98E-03	3.49E-04
4.0E-02	6.81E 00	5.21E-03	3.30E-03	4.34E-04
5.0E-02	5.79E 00	5.23E-03	4.90E-03	5.14E-04
6.0E-02	5.09E 00	5.30E-03	6.74E-03	5.90E-04
8.0E-02	4.18E 00	5.47E-03	1.11E-02	7.37E-04
1.0E-01	3.62E 00	5.70E-03	1.63E-02	8.78E-04
2.0E-01	2.46E 00	6.97E-03	5.08E-02	1.54E-03
3.0E-01	2.08E 00	8.43E-03	9.53E-02	2.17E-03
4.0E-01	1.90E 00	9.98E-03	1.46E-02	2.79E-03
5.0E-01	1.80E 00	1.15E-02	2.00E-01	3.39E-03
6.0E-01	1.74E 00	1.30E-02	2.56E-01	3.98E-03
8.0E-01	1.68E 00	1.60E-02	3.72E-01	5.09E-03
1.0E 00	1.66E 00	1.91E-02	4.91E-01	6.15E-03
2.0E 00	1.68E 00	3.53E-02	1.08E 00	1.11E-02
3.0E 00	1.74E 00	4.98E-02	1.65E 00	1.55E-02
4.0E 00	1.79E 00	6.80E-02	2.20E 00	1.97E-02
5.0E 00	1.83E 00	8.74E-02	2.73E 00	2.40E-02
6.0E 00	1.87E 00	1.07E-01	3.25E 00	2.83E-02
8.0E 00	1.93E 00	1.49E-01	4.23E 00	3.70E-02
1.0E 01	1.98E 00	1.92E-01	5.18E 00	4.56E-02
2.0E 01	2.13E 00	4.26E-01	9.44E 00	8.65E-02
3.0E 01	2.22E 00	6.73E-01	1.31E 01	1.24E-01
4.0E 01	2.27E 00	9.28E-01	1.64E 01	1.59E-01
5.0E 01	2.30E 00	1.19E 00	1.94E 01	1.90E-01
6.0E 01	2.33E 00	1.55E 00	2.21E 01	2.20E-01
8.0E 01	2.37E 00	2.09E 00	2.69E 01	2.74E-01
1.0E 02	2.40E 00	2.63E 00	3.12E 01	3.19E-01

G-2. PROTON AND He^+ ENERGY LOSS

CONTENTS

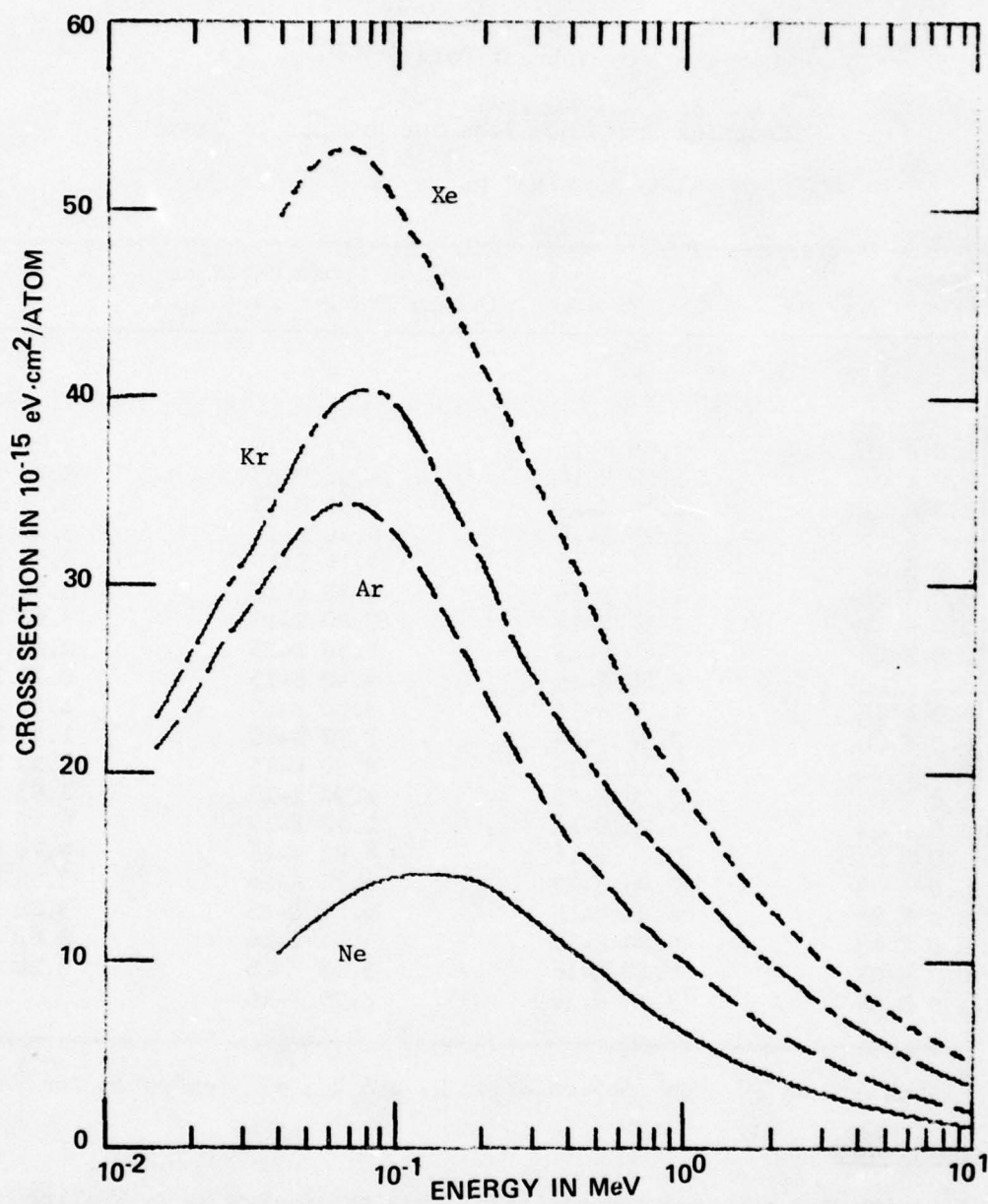
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Tabular Data G-2.1.

Stopping Cross Section for Protons in Gases

Units are Proton Energy in MeV, Cross Section in 10^{-15} eV·cm ² /atom				
Proton Energy	Stopping Cross Section			
	Neon	Argon	Krypton	Xenon
0.015		21.4	23.0	
0.020		24.0	26.6	
0.025		26.8	29.4	
0.030		28.5	31.4	
0.040	10.5	31.6	35.1	49.7
0.050	11.9	33.4	38.0	52.1
0.060	12.8	34.2	39.5	53.0
0.080	14.0	34.0	40.4	52.6
0.100	14.5	32.6	39.5	50.1
0.150	14.6	28.3	34.8	45.2
0.200	14.1	24.5	31.1	41.4
0.250	13.1	21.6	27.4	38.3
0.300	12.2	19.6	25.1	35.6
0.400	10.7	16.4	21.9	31.4
0.500	9.61	14.8	20.0	27.9
0.600	8.60	13.2	18.3	24.9
0.800	7.16	11.3	16.1	21.3
1.00	6.26	10.0	14.5	19.0
1.50	4.74	7.82	11.7	14.9
2.00	3.95	6.41	9.92	12.7
2.50	3.37	5.56	8.74	11.2
3.00	3.02	4.93	7.76	10.1
4.00	2.45	4.01	6.51	8.53
5.00	2.09	3.42	5.65	7.45
6.00	1.81	2.99	4.93	6.62
8.00	1.43	2.40	3.98	5.47
10.0	1.22	1.98	3.39	4.54
14.0	0.94	1.53	2.66	3.57
18.0	0.77	1.26	2.21	2.98
30.0	0.51	0.85	1.51	2.06

Experimental values for $E < 8$ MeV are taken from the review by W. Whaling, Handbuch der Physik, (S. Flügge, Ed., Springer-Verlag, Berlin, 1958). The data are extended to higher energies using values calculated by W. H. Barkas and M. J. Berger, "Tables of Energy Losses and Ranges of Heavy Charged Particles", NASA Report SP-3013, Washington, D. C. (1964). In the region of overlap of the two sets of data, the agreement is within 5%.



Graphical Data G-2.2.

Stopping cross section for protons in Ne, Ar, Kr, and Xe gases. Taken from W. Whaling, Handbuch der Physik, (S. Flügge, Ed., Springer-Verlag, Berlin, 1958) and W. H. Barkas and M. J. Berger, "Tables of Energy Losses and Ranges of Heavy Charged Particles", NASA Report SP-3013, Washington, D. C. (1964).

Tabular Data G-2.3.

Stopping Cross Sections for Protons in Gases

(H₂, He, N₂)

Energy (keV)	Stopping Cross Sections (eV-cm ² /target particle)		
	H ₂	He	N ₂
1.0 E 01	7.68 E-15	3.37 E-15	2.20 E-14
2.0 E 01	1.02 E-14	4.88 E-15	2.78 E-14
3.0 E 01	1.16 E-14	5.81 E-15	3.04 E-14
4.0 E 01	1.23 E-14	6.40 E-15	3.34 E-14
6.0 E 01	1.25 E-14	7.15 E-15	3.56 E-14
8.0 E 01	1.24 E-14	7.30 E-15	3.62 E-14
1.0 E 02	1.16 E-14	7.20 E-15	3.60 E-14
2.0 E 02	7.84 E-15	5.50 E-15	2.84 E-14
3.0 E 02	5.80 E-15	4.40 E-15	2.22 E-14
4.0 E 02	4.76 E-15	3.68 E-15	1.84 E-14
6.0 E 02	3.36 E-15	2.72 E-15	1.43 E-14
8.0 E 02	2.68 E-15	2.30 E-15	1.19 E-14
1.0 E 03	2.26 E-15	1.90 E-15	1.03 E-14
2.0 E 03	1.28 E-15	1.12 E-15	6.40 E-15
3.0 E 03	9.24 E-16	8.03 E-16	4.76 E-15
4.0 E 03	7.36 E-16	6.35 E-16	3.76 E-15
5.0 E 03	6.08 E-16	5.18 E-16	3.20 E-15
6.0 E 03	5.30 E-16	4.55 E-16	2.80 E-15
8.0 E 03	4.12 E-16	3.55 E-16	2.24 E-15
1.0 E 04	3.40 E-16	2.99 E-16	

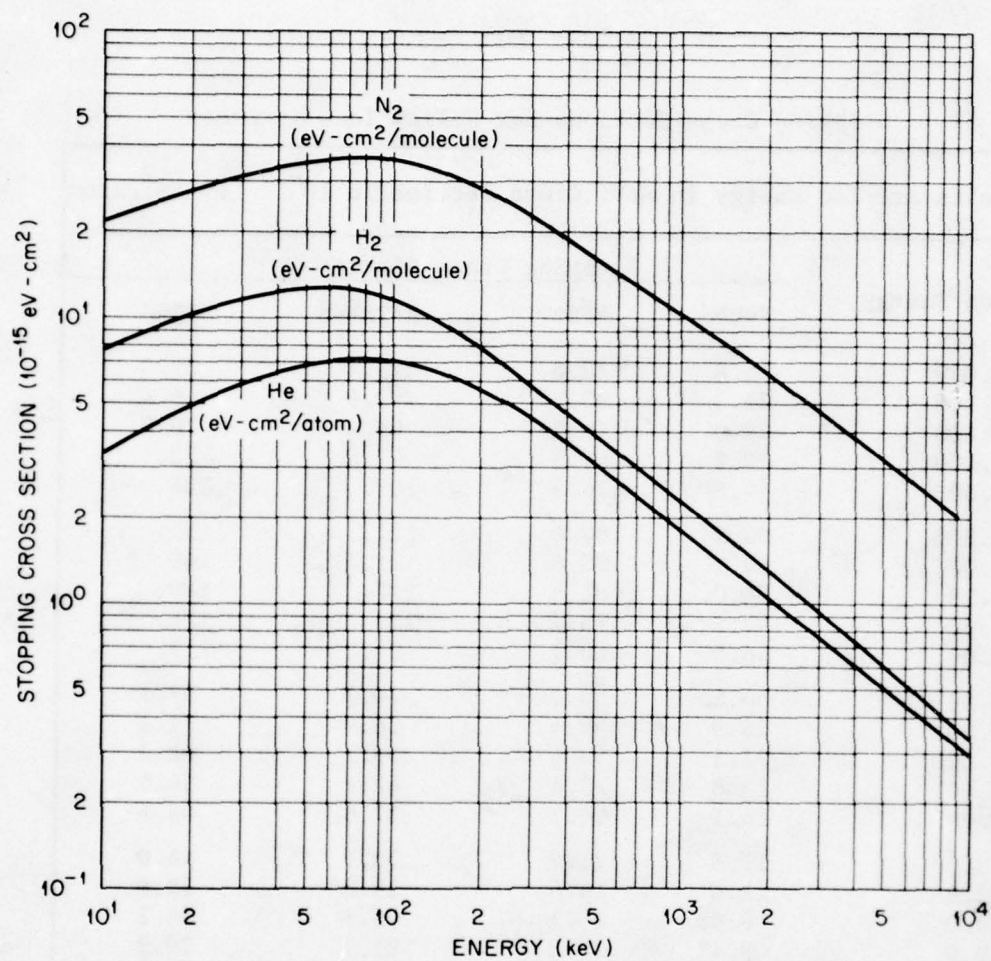
* [Data are in eV - cm²/molecule for H₂ and N₂; eV - cm²/atom for He].

Reference:

H⁺ + (H₂, He) Exp. and Theoretical: From the review by W. Whaling, Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 193.

H⁺ + N₂ Exp. and Theoretical: From the review by W. Whaling, Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 173.

Accuracy: Systematic error < + 2%. Random error < 3%.



Graphical Data G-2.4.

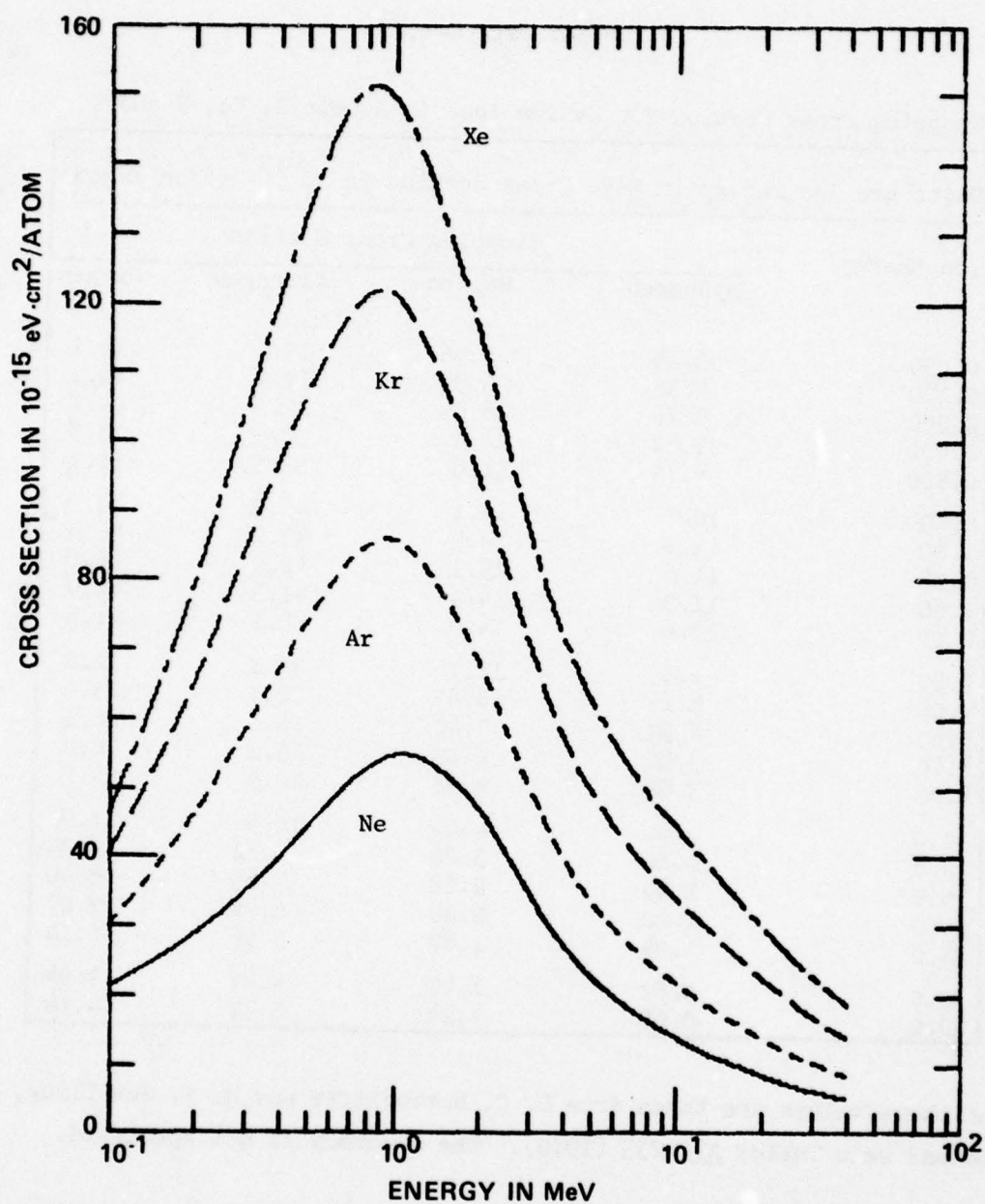
Stopping Cross Sections for Protons in H_2 , He , and Ne Gases

Tabular Data G-2.5.

Stopping Cross Sections for Helium Ions in Gases

Units are Ion Energy in MeV, Cross Section in 10^{-15} eV·cm ² /atom				
Ion Energy	Stopping Cross Section			
	Neon	Argon	Krypton	Xenon
0.050	15.8	20.6	26.4	29.4
0.100	21.3	30.2	40.6	46.4
0.200	29.0	46.3	65.4	79.8
0.400	40.2	67.5	97.8	122.
0.500	44.5	74.3	107.	134.
0.800	52.7	84.8	121.	151.
1.00	54.7	85.6	121.	149.
1.28	54.0	81.8	114.	140.
1.60	51.2	75.7	105.	128.
2.00	46.8	68.1	94.2	115.
2.80	36.8	53.2	74.7	91.1
4.00	26.9	39.4	56.9	71.1
5.00	22.5	33.4	49.2	62.3
6.40	18.8	28.4	42.7	54.5
8.00	16.1	24.7	37.8	48.6
10.0	13.8	21.7	33.7	44.0
12.8	11.6	18.6	29.8	38.8
16.0	9.95	16.1	25.9	34.2
20.0	8.41	13.8	22.5	29.9
24.0	7.34	12.1	19.9	26.4
32.0	5.86	9.82	16.1	21.8
40.0	4.96	8.29	13.8	18.5

The above values are taken from L. C. Northcliffe and R. F. Schilling, Nuclear Data Tables A7, 233 (1970). The accuracy is not specified.



Graphical Data G-2.6.

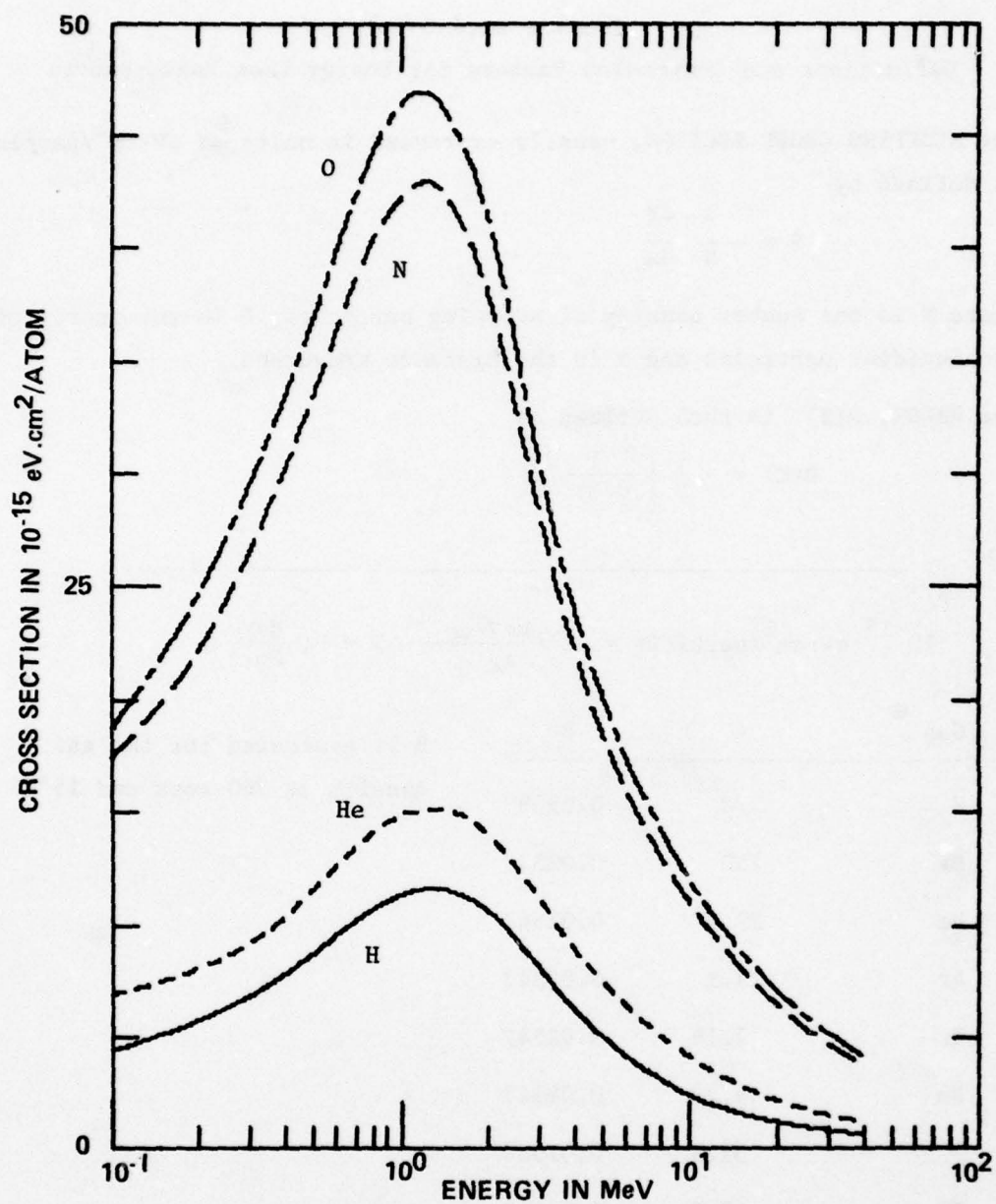
Stopping cross section for Helium ions in Ne, Ar, Kr, and Xe gases. Taken from L. C. Northcliffe and R. F. Shilling, Nuclear Data Tables A7, 233 (1970).

Tabular Data G-2.7.

Stopping Cross Section for Helium Ions in Atomic H, He, N and O

Units are Ion Energy in MeV, Cross Section in $10^{-15} \text{ eV}\cdot\text{cm}^2/\text{atom}$				
Ion Energy	Stopping Cross Section			
	Hydrogen	Helium	Nitrogen	Oxygen
0.050	3.34	5.66	13.1	14.1
0.100	4.38	6.90	17.4	18.7
0.200	5.76	8.05	22.2	24.7
0.400	7.84	10.4	30.3	33.5
0.500	8.75	11.6	33.5	36.9
0.800	10.7	14.1	40.3	44.2
1.00	11.3	14.9	42.2	46.4
1.28	11.6	15.1	42.9	46.8
1.60	11.3	14.9	41.3	44.9
2.00	10.6	14.0	38.1	41.5
2.80	8.55	11.7	30.1	32.6
4.00	6.15	8.83	22.1	23.9
5.00	4.97	7.40	18.4	20.1
6.40	3.88	6.03	15.2	16.6
8.00	3.06	4.98	12.9	14.1
10.0	2.40	4.09	10.9	11.9
12.8	1.86	3.28	9.12	9.94
16.0	1.49	2.68	7.65	8.40
20.0	1.22	2.20	6.44	7.07
24.0	1.04	1.87	5.58	6.14
32.0	0.82	1.47	4.47	4.94
40.0	0.68	1.24	3.77	4.14

The above values are taken from L. C. Northcliffe and R. F. Schilling, Nuclear Data Tables A7, 233 (1970). The accuracy is not specified.



Graphical Data G-2.8.

Stopping cross section for Helium ions in atomic H, He, N and O gases. Taken from L. C. Northcliffe and R. F. Schilling, Nuclear Data Tables A7, 233 (1970).

Tabular Data G-2.9.

Definitions and Conversion Factors for Energy Loss Measurements

The STOPPING CROSS SECTION, usually expressed in units of $\text{eV}\cdot\text{cm}^2/\text{particle}$ is defined by

$$S = - \frac{1}{N} \frac{dE}{dx}$$

where N is the number density of stopping particles, E is the energy of the incident particles and x is the distance traversed.

The RANGE, $R(E)$, is then defined as

$$R(E) = - \frac{1}{N} \int_0^E \frac{1}{S(E)} dE$$

$$10^{-15} \text{ eV}\cdot\text{cm}^2/\text{particle} = A \left(\frac{\text{keV}\cdot\text{cm}^2}{\text{mg}} \right) = B \left(\frac{\text{MeV}}{\text{cm}} \right)$$

Gas	A	B	B is evaluated for the gas density at 760 torr and 15°C.
H ₂	598	0.0509	
He	150	0.02547	
Ne	29.8	0.02547	
Ar	15.1	0.02547	
Kr	7.19	0.02547	
Xe	4.59	0.02547	
F	31.7	0.02547	
Cl	17.0	0.02547	
N ₂	43.0	0.0509	
O ₂	38.8	0.0509	
CO ₂	13.68	0.0764	

Reference: W. Whaling, Handbuch der Physik, (S. Flügge, Ed., Springer Verlag, Berlin, 1958), Volume 34, page 213.

G-3. PROTON AND He^+ RANGE

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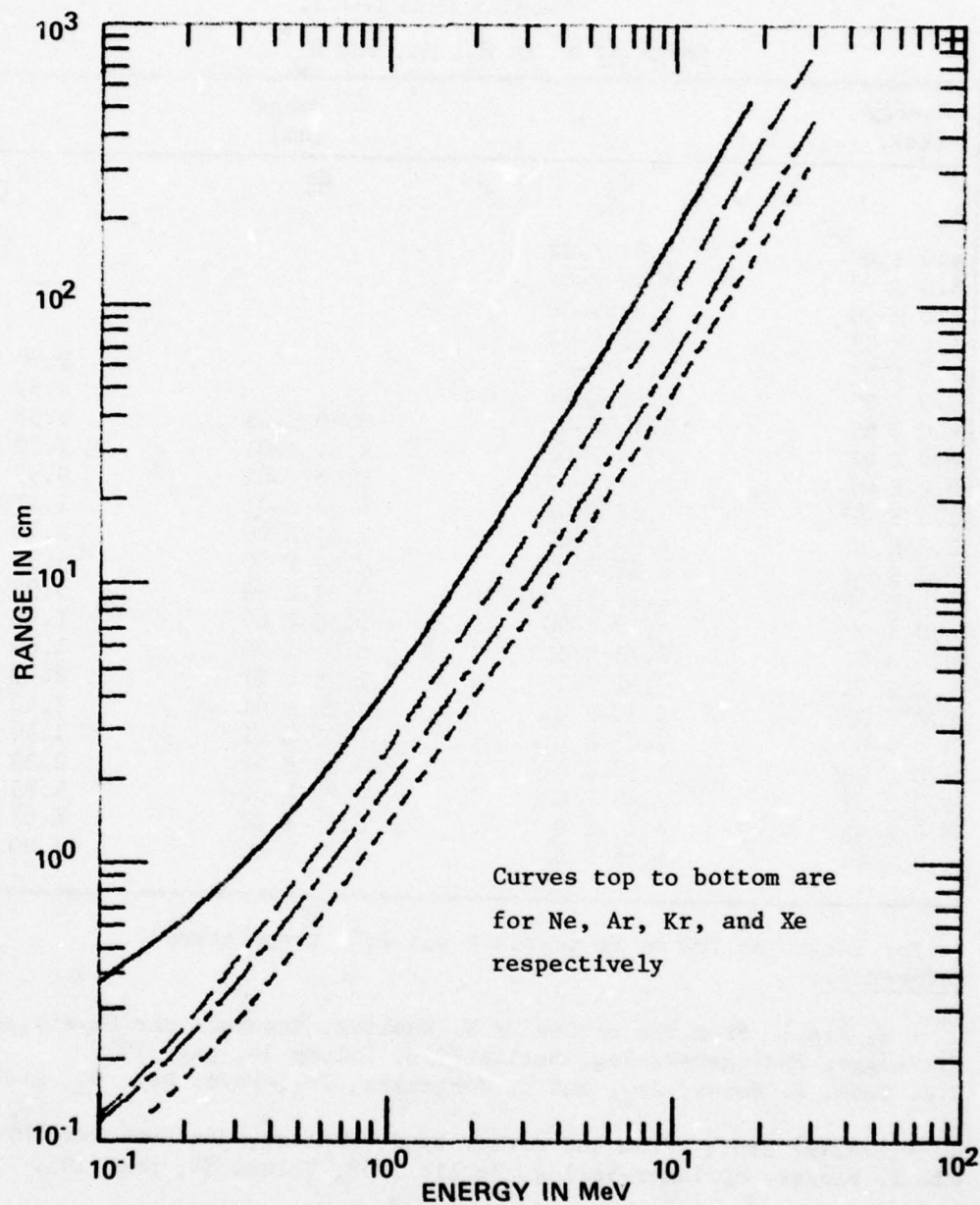
Tabular Data G-3.1.

Proton Range in Ne, Ar, Kr, and Xe

Units are Proton Energy in MeV, Range in cm. The gases are assumed to be at 760 torr and 15 °C.

Proton Energy	Range			
	Neon	Argon	Krypton	Xenon
0.04		0.054		
0.06		0.077		
0.08		0.100		
0.10	0.372	0.124	0.119	0.087
0.15	0.504	0.188	0.172	0.128
0.20	0.639	0.263	0.233	0.173
0.30	0.939	0.444	0.374	0.275
0.40	1.28	0.663	0.540	0.393
0.60	2.10	1.20	0.933	0.676
0.80	3.11	1.84	1.39	1.02
1.00	4.29	2.58	1.91	1.41
1.50	7.93	4.86	3.44	2.57
2.00	12.5	7.66	5.27	3.99
3.00	24.0	14.7	9.79	7.47
4.00	38.5	23.6	15.3	11.7
5.00	56.0	34.3	21.9	16.6
6.00	76.4	46.7	29.3	22.2
8.00	125.	76.4	47.1	35.4
10.0	185.	113.	68.7	51.1
14.0	337.	210.	125.	93.5
18.0	526.	326.	191.	142.
30.0	1311.	800.	460.	339.

Experimental values for $E \leq 10$ MeV are taken from the review by W. Whaling, Handbuch der Physik, (S. Flügge, Ed., Springer-Verlag, Berlin, 1958). The data are extended to higher energies using values calculated by W. H. Barkas and M. J. Berger, "Tables of Energy Losses and Ranges of Heavy Charged Particles", NASA Report SP-3013, Washington, D. C. (1964). In the region of overlap of the two sets of data, the agreement is within 5%.



Graphical Data G-3.2.

Range of protons in Ne, Ar, Kr, and Xe gases at 760 torr and 15°C. Taken from W. Whaling, Handbuch der Physik, (S. Flügge, Ed., Springer-Verlag, Berlin, 1958) and W. H. Barkas and M. J. Berger, "Tables of Energy Losses and Ranges of Heavy Charged Particles", NASA Report SP-3013, Washington, D. C. (1964).

Tabular Data G-3.3.
Range of H^+ in H_2 , He, and N_2 *

Energy (keV)	Range (cm)		
	H_2	He	N_2
4.0 E 00	3.87 E-02		
6.0 E 00	4.92 E-02		
8.0 E 00	5.83 E-02		
1.0 E 01	6.75 E-02		
2.0 E 01	1.10 E-01		3.50 E-02
3.0 E 01	1.43 E-01		4.59 E-02
4.0 E 01	1.74 E-01	3.46 E-01	5.58 E-02
6.0 E 01	2.36 E-01	4.61 E-01	7.50 E-02
8.0 E 01	2.97 E-01	5.68 E-01	9.55 E-02
1.0 E 02	3.62 E-01	6.74 E-01	1.17 E-01
2.0 E 02	7.80 E-01	1.29 E 00	2.40 E-01
3.0 E 02	1.37 E-00	2.09 E 00	3.98 E-01
4.0 E 02	2.13 E-00	3.07 E 00	5.93 E-01
6.0 E 02	4.12 E-00	5.53 E 00	1.08 E 00
8.0 E 02	6.72 E-00	8.65 E 00	1.69 E 00
1.0 E 03	9.91 E-00	1.25 E 01	2.49 E 00
2.0 E 03	3.38 E 01	4.04 E 01	7.42 E 00
3.0 E 03	7.03 E 01	8.28 E 01	1.46 E 01
4.0 E 03	1.18 E 02	2.87 E 02	2.39 E 01
6.0 E 03	2.46 E 02	4.83 E 02	4.85 E 01
8.0 E 03	4.17 E 02	5.98 E 02	8.07 E 01
1.0 E 04	6.28 E 02	7.24 E 02	1.20 E 02

* [For target at 760 mm Hg pressure and 15°C temperature].

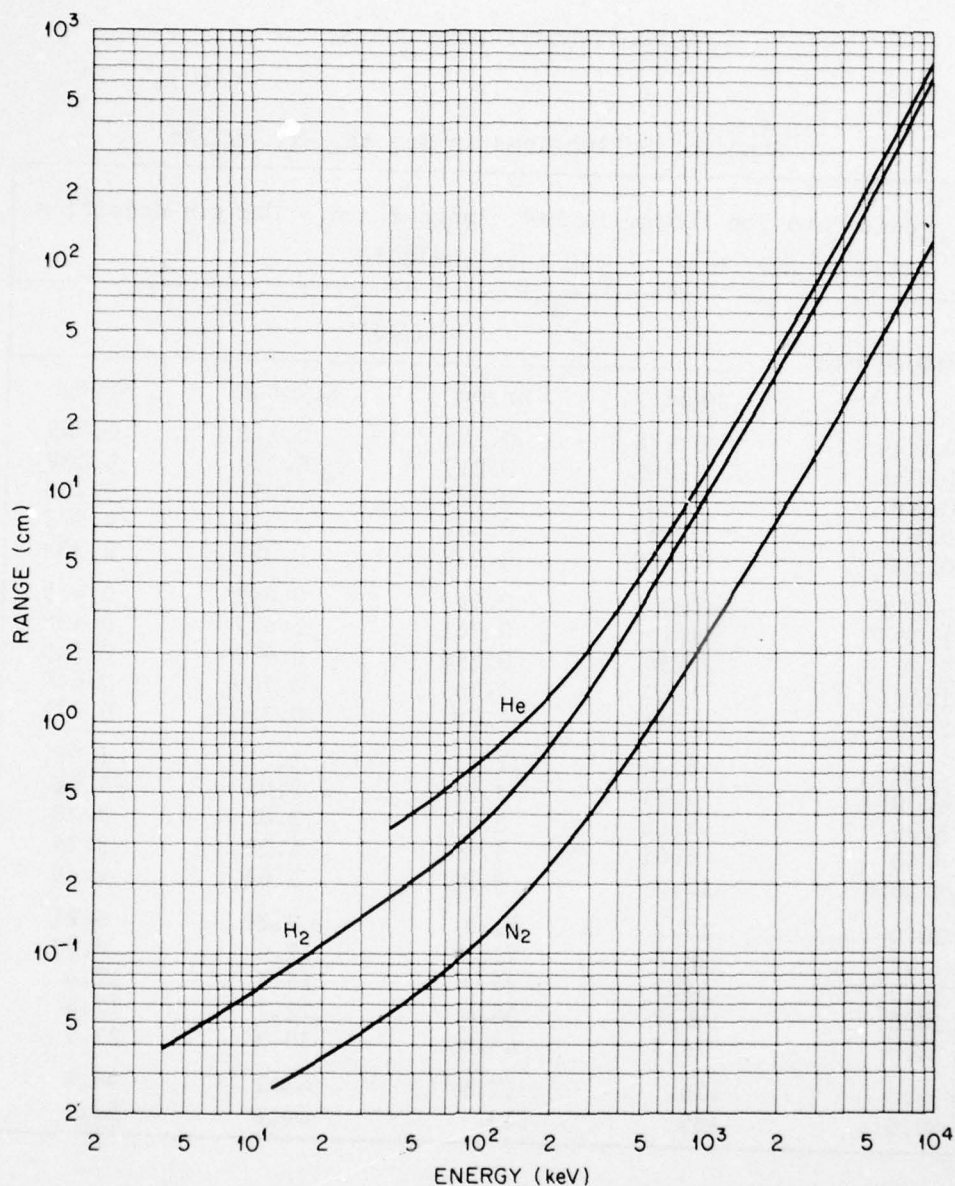
References:

H^+ + H_2 Exp.: From the review by W. Whaling, Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 193.
C.J. Cook, E. Jones, Jr., and T. Jorgensen, Jr., Phys. Rev. 91, 1417 (1953).

H^+ + (He, N_2) Exp.: From the review by W. Whaling, Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 193.

A distinction between "mean range" and "extrapolated ionization range" is made by W. Whaling [Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 193]. In general the difference is small, and the distinction has not been observed here.

An extensive tabulation of semi-empirical data for various projectiles and targets is to be found in the work of L. C. Northcliffe and R. F. Schilling, Nuclear Data Tables A 7, 233 (1970). This also provides prescriptions for interpolation to any media.



Graphical Data G-3.4.

Range of H^+ in H_2 , He, and N_2 Gases at 760 torr and 15°C.

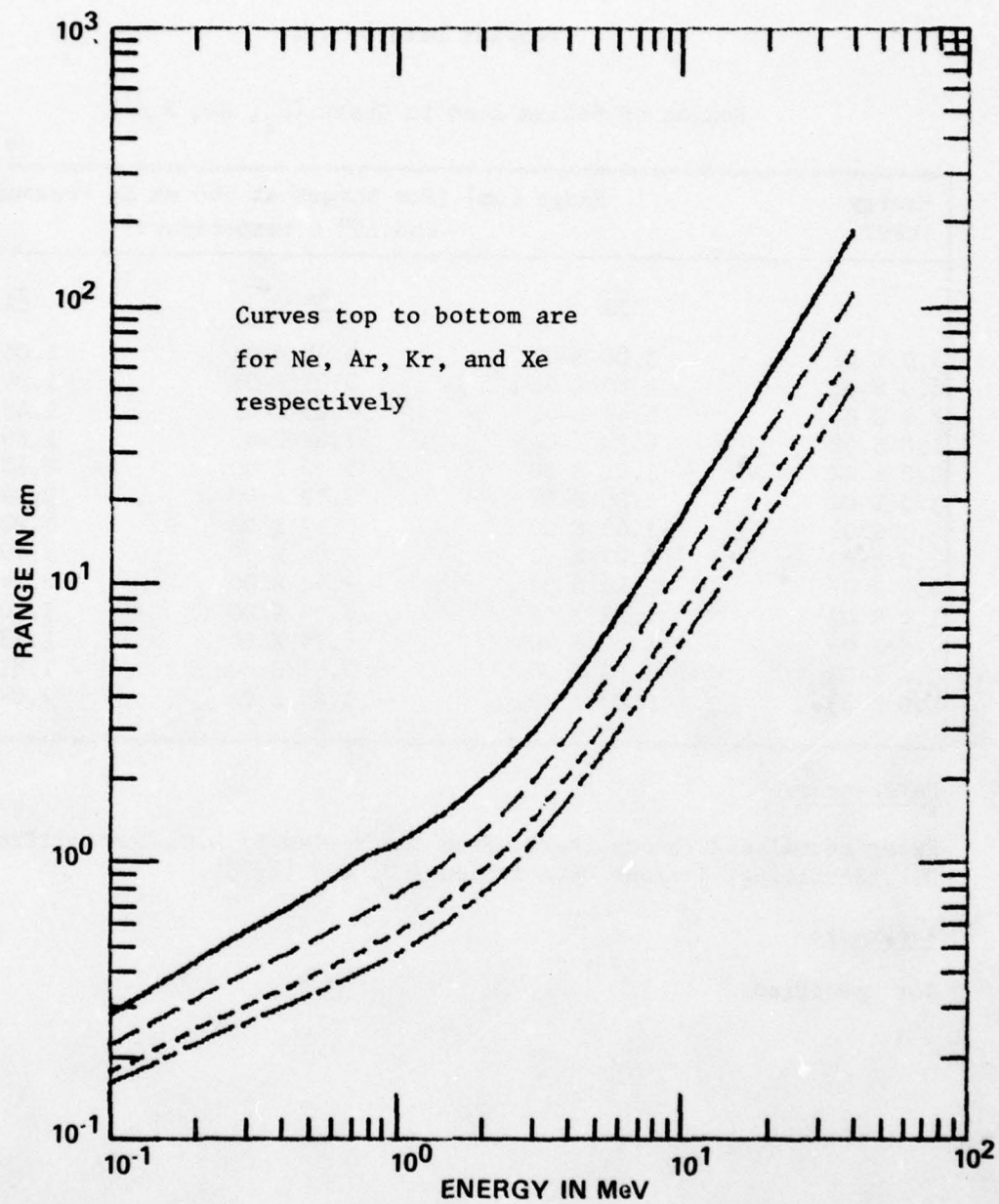
At the lowest energies of this table, the range R and energy $E(\text{keV})$ are related by $R = KE^n$. Data may be extrapolated down to lower energies using: $K = 0.0147$, $n = 0.67$ for H_2 ; $K = 0.00439$, $n = 0.71$ for N_2 .

Tabular Data G-3.5.

Range of Helium Ions in Ne, Ar, Kr, and Xe

Units are Ion Energy in MeV, Range in cm. The gas densities assumed are those at 760 torr and 20°C.				
Ion Energy	Range			
	Neon	Argon	Krypton	Xenon
0.050	0.178	0.143	0.118	0.109
0.100	0.281	0.219	0.176	0.160
0.200	0.437	0.323	0.251	0.223
0.400	0.667	0.462	0.349	0.302
0.500	0.762	0.518	0.388	0.333
0.800	1.05	0.667	0.492	0.415
1.00	1.16	0.761	0.557	0.468
1.28	1.36	0.894	0.652	0.545
1.60	1.60	1.06	0.769	0.640
2.00	1.93	1.28	0.930	0.771
2.80	2.70	1.81	1.31	1.08
4.00	4.25	2.87	2.06	1.68
5.00	5.88	3.98	2.82	2.28
6.40	8.61	5.80	4.04	3.24
8.00	12.3	8.22	5.64	4.48
10.0	17.7	11.7	7.88	6.21
12.8	26.5	17.3	11.4	8.91
16.0	38.5	24.7	16.1	12.4
20.0	56.0	35.4	22.7	17.4
24.0	76.5	47.8	30.3	23.1
32.0	126.	77.3	48.2	36.4
40.0	185	113.	69.8	52.3

The above values are taken from L. C. Northcliffe and R. F. Schilling, Nuclear Data Tables A7, 233 (1970). The accuracy is not specified.



Graphical Data G-3.6.

Range of Helium ions in Ne, Ar, Kr, and Xe gases at 760 torr and 20°C.
Taken from L. C. Northcliffe and R. F. Schilling, Nuclear Data Tables
A7, 233 (1970).

Tabular Data G-3.7.

Ranges of Helium Ions in Gases (H_2 , He, N_2)

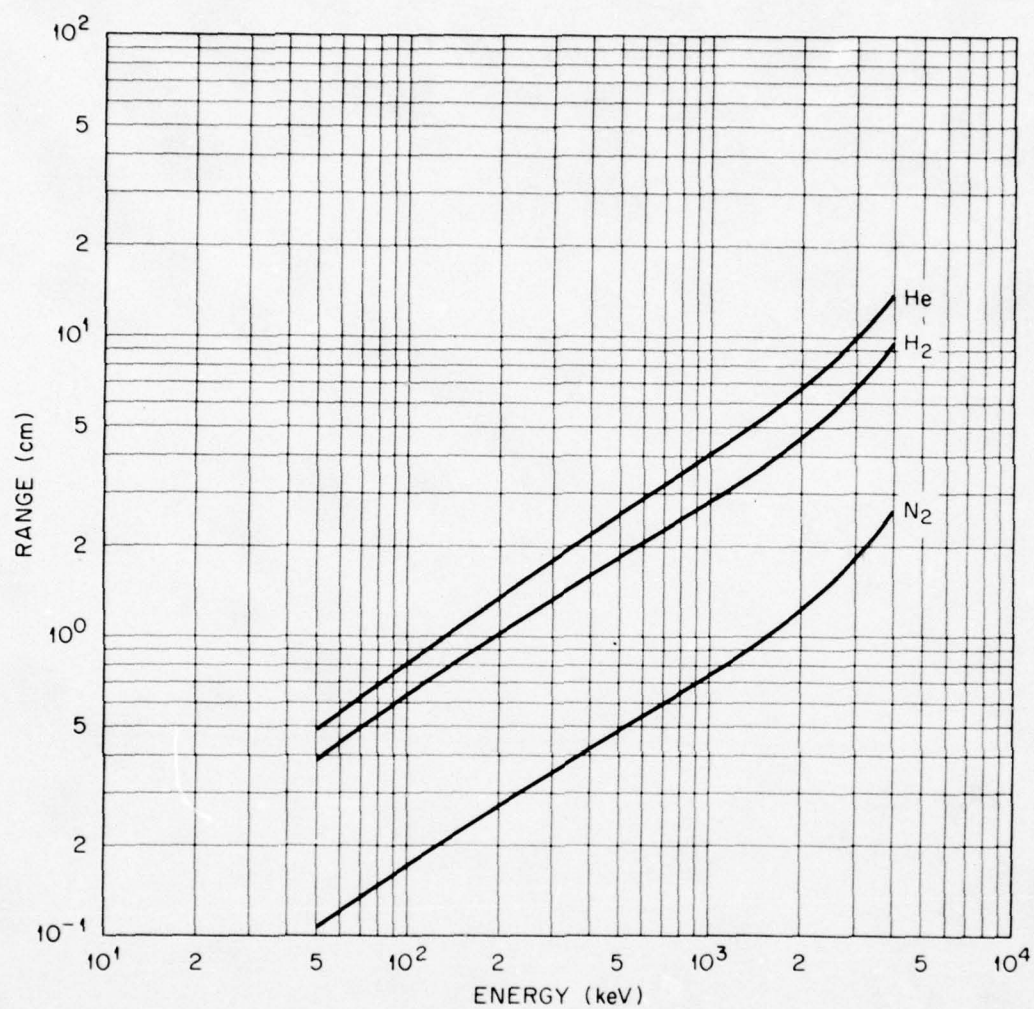
Energy (keV)	Range (cm) [For target at 760 mm Hg Pressure and 15° C temperature]		
	<u>H_2</u>	<u>He</u>	<u>N_2</u>
5.0 E 01	3.82 E-01	4.88 E-01	1.05 E-01
6.0 E 01	4.40 E-01	5.55 E-01	1.20 E-01
8.0 E 01	5.42 E-01	6.85 E-01	1.45 E-01
1.0 E 02	6.34 E-01	7.92 E-01	1.69 E-01
2.0 E 02	1.01 E 00	1.32 E 00	2.68 E-01
3.0 E 02	1.31 E 00	3.79 E 00	3.49 E-01
4.0 E 02	1.60 E 00	2.19 E 00	4.20 E-01
6.0 E 02	2.03 E 00	2.89 E 00	5.40 E-01
8.0 E 02	2.46 E 00	3.48 E 00	6.44 E-01
1.0 E 03	2.82 E 00	4.04 E 00	7.40 E-01
2.0 E 03	4.60 E 00	6.75 E 00	1.23 E 00
3.0 E 03	6.80 E 00	9.80 E 00	1.81 E 00
4.0 E 03	9.61 E 00	1.40 E 01	2.64 E 00

References:

Experimental and Theoretical: From the review by L.C. Northcliffe and R.F. Schilling, Nuclear Data Tables A 7, 233 (1970).

Accuracy:

Not specified.



Graphical Data G-3.8.
Ranges of Helium Ions in H_2 , He , and N_2 Gases at 760 torr
and $15^\circ C$

G-4. AVERAGE ENERGY EXPENDED TO CREATE AN ION PAIR

CONTENTS

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Average Energy per Ion Pair for Alpha and Beta Particles in He, Ne, Ar, Kr, Xe, H ₂ , N ₂ , O ₂ , CO, CO ₂ , BF ₃ and CCl ₂ F ₂	814

Tabular Data G-4.

W = Average Energy Expended by a Charged Particle
to Create an Ion Pair

Units of energy are electron volts. W_α, W_β denote alpha particle,
electron respectively as the incident particle, I = ionization energy.

Target Gas	W_α	W_β	I
He	46.0	42.3	24.581
Ne	36.55	36.4	21.559
Ar	26.4	26.3	15.755
Kr	24.00	24.05	13.996
Xe	21.7	21.9	12.127
H ₂	36.4	36.30	15.43
N ₂	36.39	34.65	15.59
O ₂	32.23	30.83	12.15
CO	34.65	32.75	14.04
CO ₂	34.26	32.80	13.81
BF ₃	35.63		15.83
CCl ₂ F ₂	29.55		11.8

The above values are taken from L. G. Christophorou, Atomic and Molecular Radiation Physics, Wiley-Interscience, New York, 1971. They represent the author's best estimate of the true value, based on the several experimental values available.

G-5. CHARGE STATE POPULATIONS

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G-5.9 Equilibrium Fractions of a Helium Beam in Ar. . . .	824-25.

Tabular Data G-5.1.

Equilibrium Fractions of a Hydrogen Beam in He and Ar.

Energy (keV)	Equilibrium Fractions					
	He			Ar		
	$F_{1\infty}$	$F_{0\infty}$	$F_{1\infty}$	$F_{1\infty}$	$F_{0\infty}$	$F_{1\infty}$
4.0 E 00		1.25 E-01	9.00 E-01	4.00 E-02	9.20 E-01	5.50 E-02
6.0 E 00		2.38 E-01	7.60 E-01	3.10 E-03	8.80 E-01	9.30 E-02
8.0 E 00		3.35 E-01	6.55 E-01	2.00 E-02	8.50 E-01	1.32 E-01
1.0 E 01		4.10 E-01	5.80 E-01	1.30 E-02	8.20 E-01	1.67 E-01
2.0 E 01	9.20 E-03	6.00 E-01	3.90 E-01	5.00 E-03	6.75 E-01	3.25 E-01
3.0 E 01	9.55 E-03	6.00 E-01	3.95 E-01		5.75 E-01	4.30 E-01
4.0 E 01		5.45 E-01	4.50 E-01		4.85 E-01	5.15 E-01
6.0 E 01		4.40 E-01	5.55 E-01		3.55 E-01	6.50 E-01
8.0 E 01		3.35 E-01	6.75 E-01		2.50 E-01	7.50 E-01
1.0 E 02		2.54 E-01	7.45 E-01		1.75 E-01	8.40 E-01
2.0 E 02		6.05 E-02	9.40 E-01		3.10 E-02	9.50 E-01
3.0 E 02		1.75 E-02	9.60 E-01		8.30 E-03	9.90 E-01
4.0 E 02		6.45 E-03	9.80 E-01		3.25 E-03	9.98 E-01
6.0 E 02		1.55 E-03	1.00 E 00		1.00 E-03	1.00 E 00
8.0 E 02		5.20 E-04	1.00 E 00		8.93 E-04	1.00 E 00
1.0 E 03		3.60 E-04	1.00 E 00		1.20 E-04	1.00 E 00

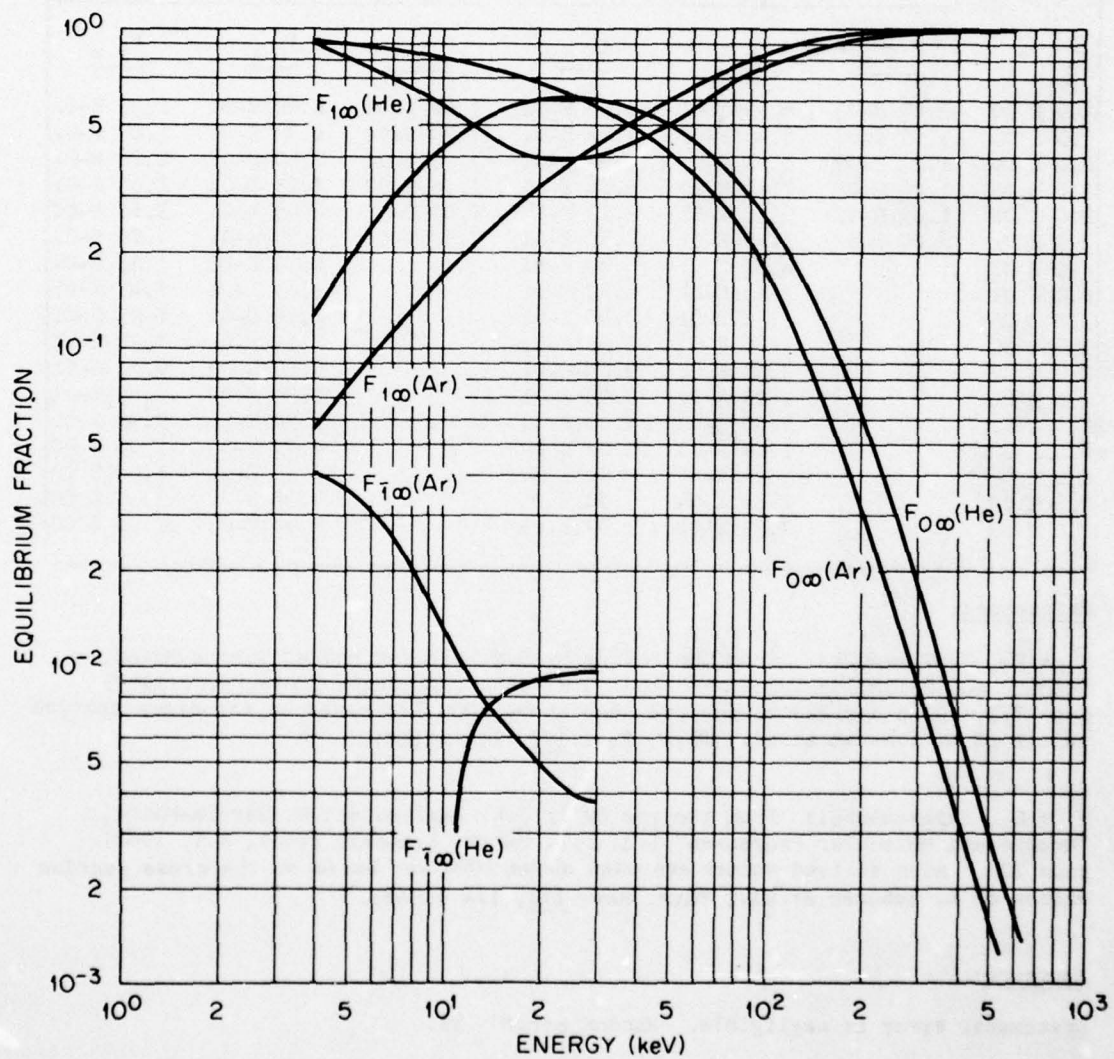
References:

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Accuracy:

Systematic error is negligible. Random error < $\pm 5\%$.



Graphical Data G-5.2.

Equilibrium Fractions of a Hydrogen Beam in He and Ar Gases.

Tabular Data G-5.3.

Equilibrium Fractions of a Hydrogen Beam in N_2 and O_2

Energy (keV)	Equilibrium Fractions					
	N_2			O_2		
	$F_{1\infty}$	$F_{0\infty}$	$F_{1\infty}$	$F_{1\infty}$	$F_{0\infty}$	$F_{1\infty}$
4.0 E 00	3.70 E-03	8.90 E-01	1.25 E-01	1.66 E-02	8.60 E-01	1.35 E-01
6.0 E 00	9.05 E-03	8.45 E-01	1.62 E-01	1.78 E-02	8.00 E-01	1.87 E-01
8.0 E 00	1.23 E-02	8.00 E-01	1.95 E-01	1.70 E-02	7.60 E-02	2.28 E-01
1.0 E 01	1.36 E-02	7.60 E-01	2.24 E-01	1.56 E-02	7.25 E-01	2.63 E-01
2.0 E 01	1.00 E-02	6.40 E-01	3.50 E-01	1.05 E-02	6.05 E-01	3.85 E-01
3.0 E 01	6.05 E-03	5.45 E-01	4.55 E-01	7.50 E-03	5.30 E-01	4.70 E-01
4.0 E 01		4.80 E-01	5.40 E-01		4.70 E-01	5.38 E-01
6.0 E 01		3.55 E-01	6.55 E-01		3.65 E-01	6.45 E-01
8.0 E 01		2.55 E-01	7.40 E-01		2.80 E-01	7.25 E-01
1.0 E 02		1.86 E-01	8.05 E-01		2.12 E-01	7.75 E-01
2.0 E 02		3.60 E-02	9.60 E-01		5.10 E-02	9.40 E-01
3.0 E 02		1.00 E-02	9.90 E-01		1.54 E-02	9.80 E-01
4.0 E 02		4.05 E-03	1.00 E 00		6.50 E-03	9.90 E-01
6.0 E 02		1.14 E-03	1.00 E 00		1.95 E-03	1.00 E 00
8.0 E 02		5.00 E-04	1.00 E 00		7.64 E-04	1.00 E 00
1.0 E 03		2.80 E-04	1.00 E 00		4.38 E-04	1.00 E 00
2.0 E 03		7.53 E-05	1.00 E 00		6.90 E-05	1.00 E 00

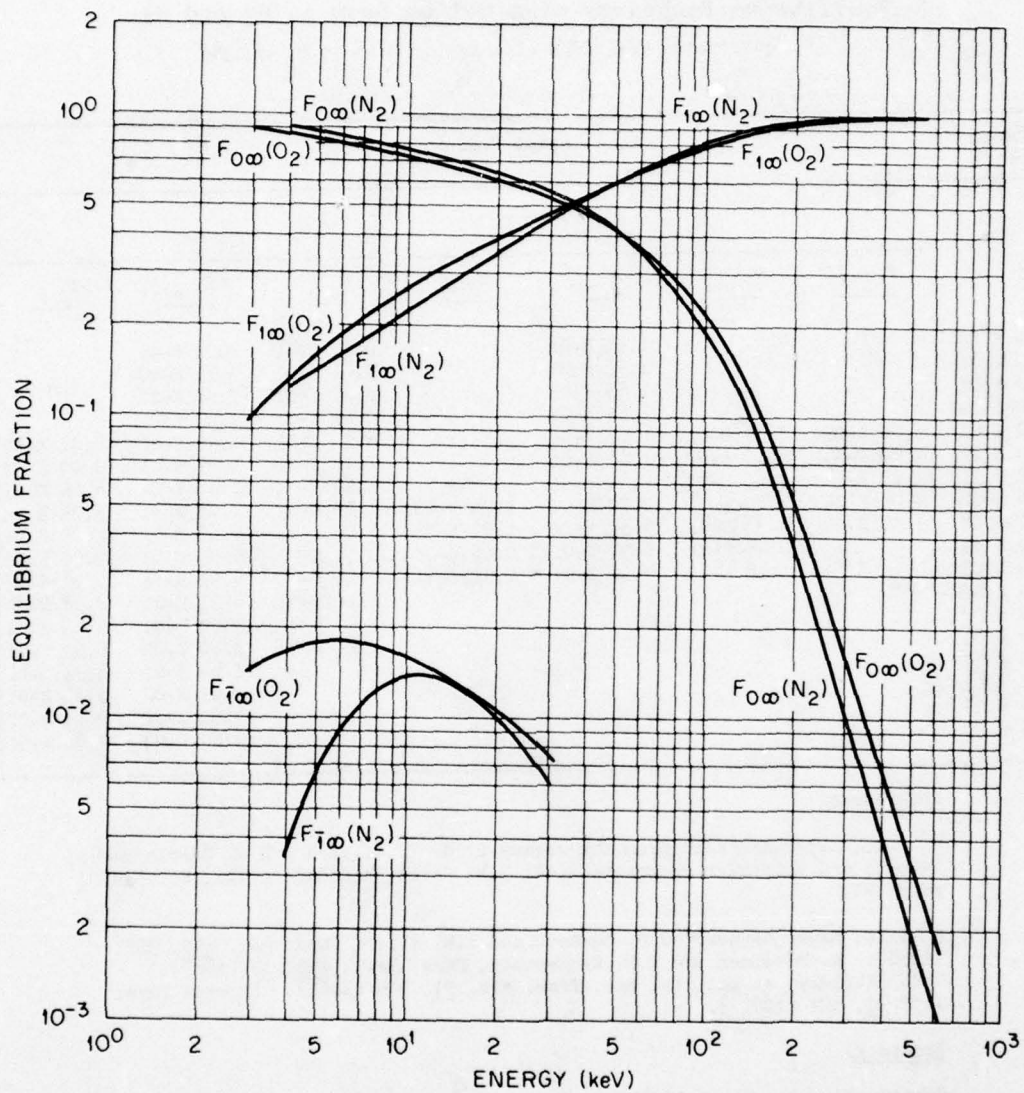
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$H^+ + O_2$, Experimental: From the review by S.K. Allison and M. Garcia-Munoz, "Atomic and Molecular Processes" (ed. D.R. Bates, Academic Press, N.Y. 1962) page 721. Also derived values are used above 1000 keV based on the cross section values of L. Toburen et al., Phys. Rev. 171, 114 (1968).

Accuracy:

Systematic error is negligible. Random error < 5%.



Graphical Data G-5.4.

Equilibrium Fractions of a Hydrogen Beam in N_2 and O_2 Gases

Tabular Data G-5.5.

Equilibrium Fractions of a Helium Beam in H₂ and He.

Equilibrium Fractions of a Helium Beam in H₂ and He

Energy (keV)	Equilibrium Fractions						
	H ₂				He		
	$F_{1\infty}$	$F_{0\infty}$	$F_{1\infty}$	$F_{2\infty}$	$F_{0\infty}$	$F_{1\infty}$	$F_{2\infty}$
8.0 E 00			1.51 E-01		9.70 E-01	2.90 E-02	
1.0 E 01			1.57 E-01		9.62 E-01	3.71 E-02	
2.0 E 01			1.63 E-01		9.05 E-01	7.50 E-02	
3.0 E 01			1.64 E-01		8.65 E-01	1.09 E-01	
4.0 E 01	5.20 E-05	8.30 E-01	1.68 E-01		8.30 E-01	1.40 E-01	2.42 E-03
6.0 E 01	1.00 E-04	8.10 E-01	1.98 E-01		7.90 E-01	1.99 E-01	3.40 E-03
8.0 E 01	1.60 E-04	7.60 E-01	2.40 E-01		7.60 E-01	2.50 E-01	4.66 E-03
1.0 E 02	2.00 E-04	7.00 E-01	2.89 E-01	1.00 E-03	7.07 E-01	2.94 E-01	6.26 E-03
2.0 E 02	1.70 E-04	4.38 E-01	5.50 E-01	1.23 E-02	5.00 E-01	4.68 E-01	2.05 E-02
3.0 E 02		2.46 E-01	6.90 E-01	6.68 E-02	3.60 E-01	5.90 E-01	5.00 E-02
4.0 E 02		1.18 E-01	7.30 E-01	1.67 E-01	2.51 E-01	6.49 E-01	9.90 E-02
6.0 E 02					1.14 E-01	6.23 E-01	2.58 E-01
8.0 E 02					4.99 E-02	5.20 E-01	4.63 E-01
1.0 E 03					1.94 E-02	3.80 E-01	6.00 E-01
2.0 E 03						1.04 E-01	8.51 E-01
3.0 E 03						3.91 E-02	9.35 E-01
4.0 E 03						1.80 E-02	9.70 E-01
5.0 E 03						9.60 E-03	9.86 E-01

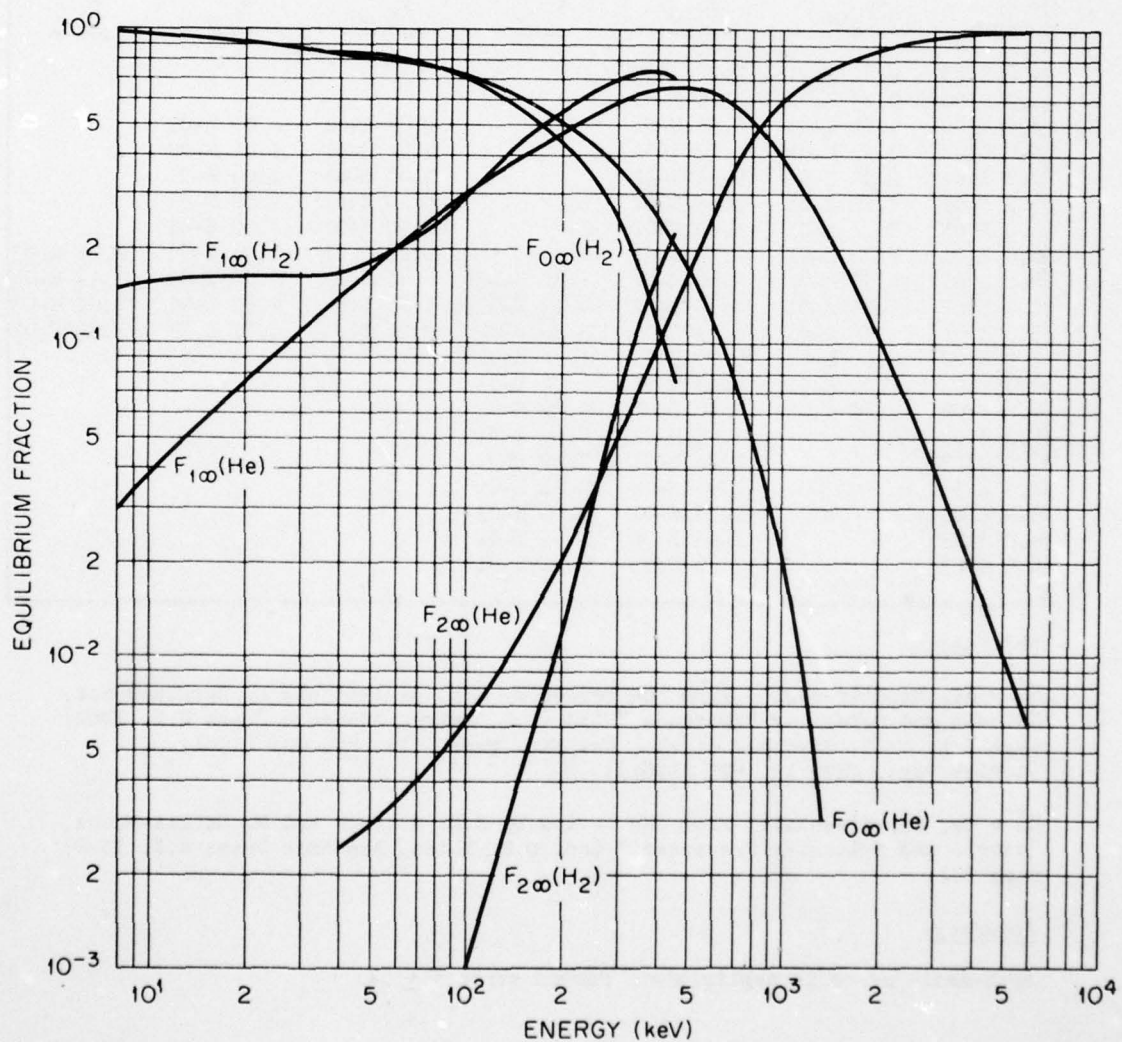
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H⁺ + He, Experimental: C.F. Barnett and P.M. Stier, Phys. Rev. 109, 385 (1958). W. Meckbach and I.B. Nemirovsky, Phys. Rev., 153, 13 (1967). V.S. Nikolaev, et al., Zh. Eks. Teor. Fiz. 39, 905 (1961). [Soviet Phys. JETP 12, 627 (1961)].

Accuracy:

Systematic error is negligible. Random error < + 5%.



Graphical Data G-5.6.
Equilibrium Fractions of a Helium Beam in H_2 and He Gases.

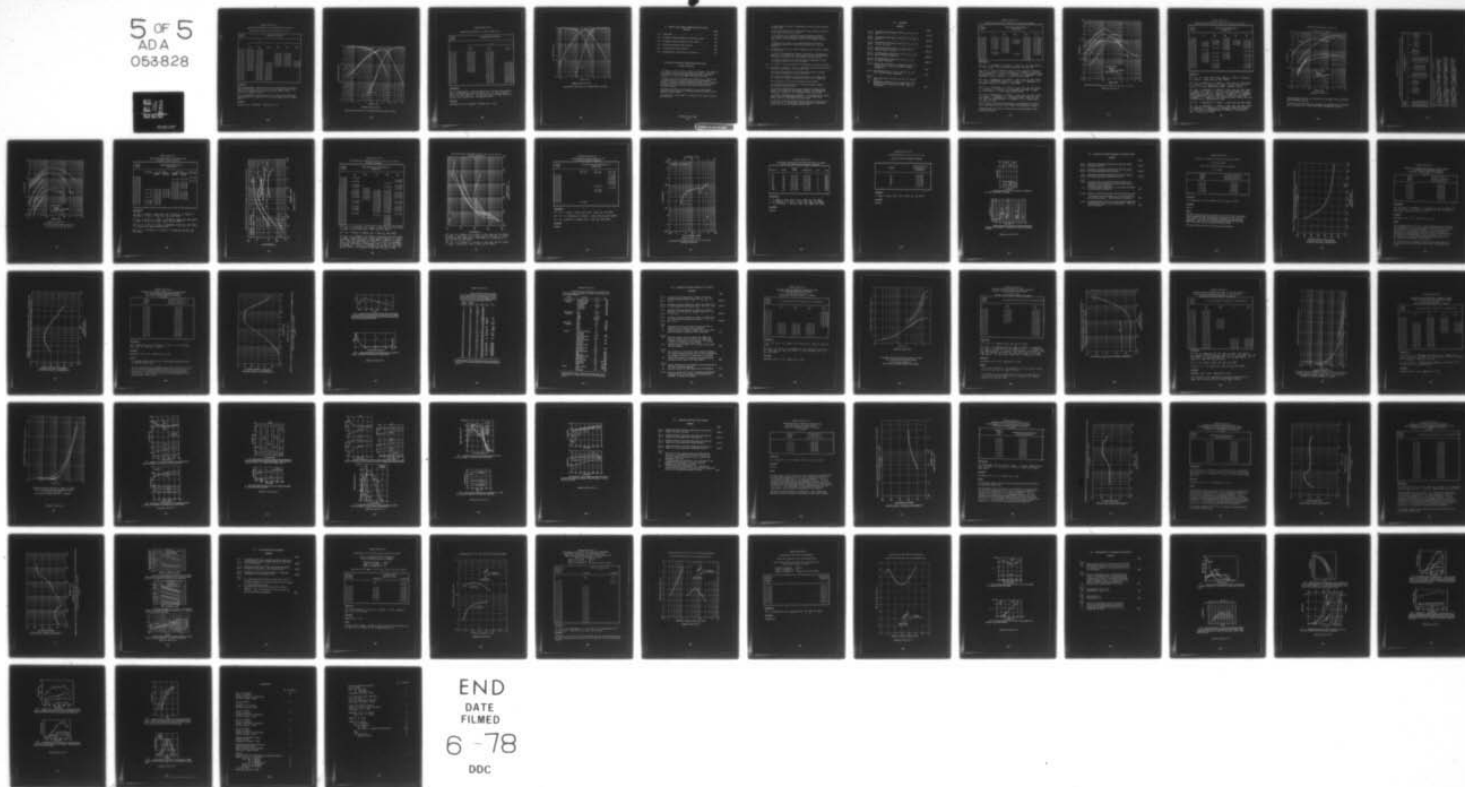
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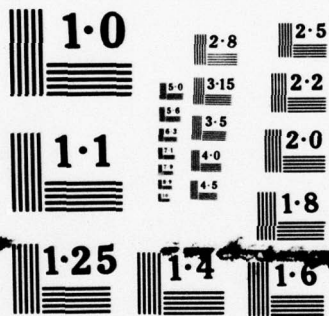
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MICROCOPY RESOLUTION TEST CHART

Tabular Data G-5.7.

Equilibrium Fractions of a Helium Beam in N₂ and O₂

Equilibrium Fractions of a Helium Beam in N₂ and O₂

Energy (keV)	Equilibrium Fractions					
	N ₂			O ₂		
	<u>F₀ ∞</u>	<u>F₁ ∞</u>	<u>F₂ ∞</u>	<u>F₀ ∞</u>	<u>F₁ ∞</u>	<u>F₂ ∞</u>
4.0 E 00	9.80 E-01	2.02 E-02				
6.0 E 00	9.63 E-01	2.75 E-02				
8.0 E 00	9.64 E-01	3.58 E-02		9.73 E-01	2.70 E-01	
1.0 E 01	9.55 E-01	4.42 E-02		9.61 E-01	3.91 E-02	
2.0 E 01	9.06 E-01	9.42 E-02		9.00 E-01	1.00 E-01	
3.0 E 01	8.57 E-01	1.43 E-01		8.50 E-01	1.50 E-01	
4.0 E 01	8.12 E-01	1.90 E-01		8.00 E-01	2.00 E-01	
6.0 E 01	7.24 E-01	2.76 E-01		7.09 E-01	2.91 E-01	2.02 E-03
8.0 E 01	6.50 E-01	3.50 E-01	2.36 E-03	6.40 E-01	3.56 E-01	4.18 E-03
1.0 E 02	5.84 E-01	4.12 E-01	4.13 E-03	5.83 E-01	4.10 E-01	7.02 E-03
2.0 E 02	3.46 E-01	6.19 E-01	3.50 E-02	3.86 E-01	5.81 E-01	3.39 E-02
3.0 E 02	2.00 E-01	6.90 E-01	1.10 E-01			
4.0 E 02	1.08 E-01	6.89 E-01	2.04 E-01			
6.0 E 02	3.80 E-02	5.70 E-01	3.99 E-01			
8.0 E 02		3.95 E-01	5.65 E-01			
1.0 E 03		2.80 E-01	7.20 E-01			
2.0 E 03		7.90 E-02	9.21 E-01			
3.0 E 03		3.38 E-02	9.66 E-01			
4.0 E 03		1.80 E-02	9.91 E-01			
6.0 E 03		7.50 E-03	9.92 E-01			

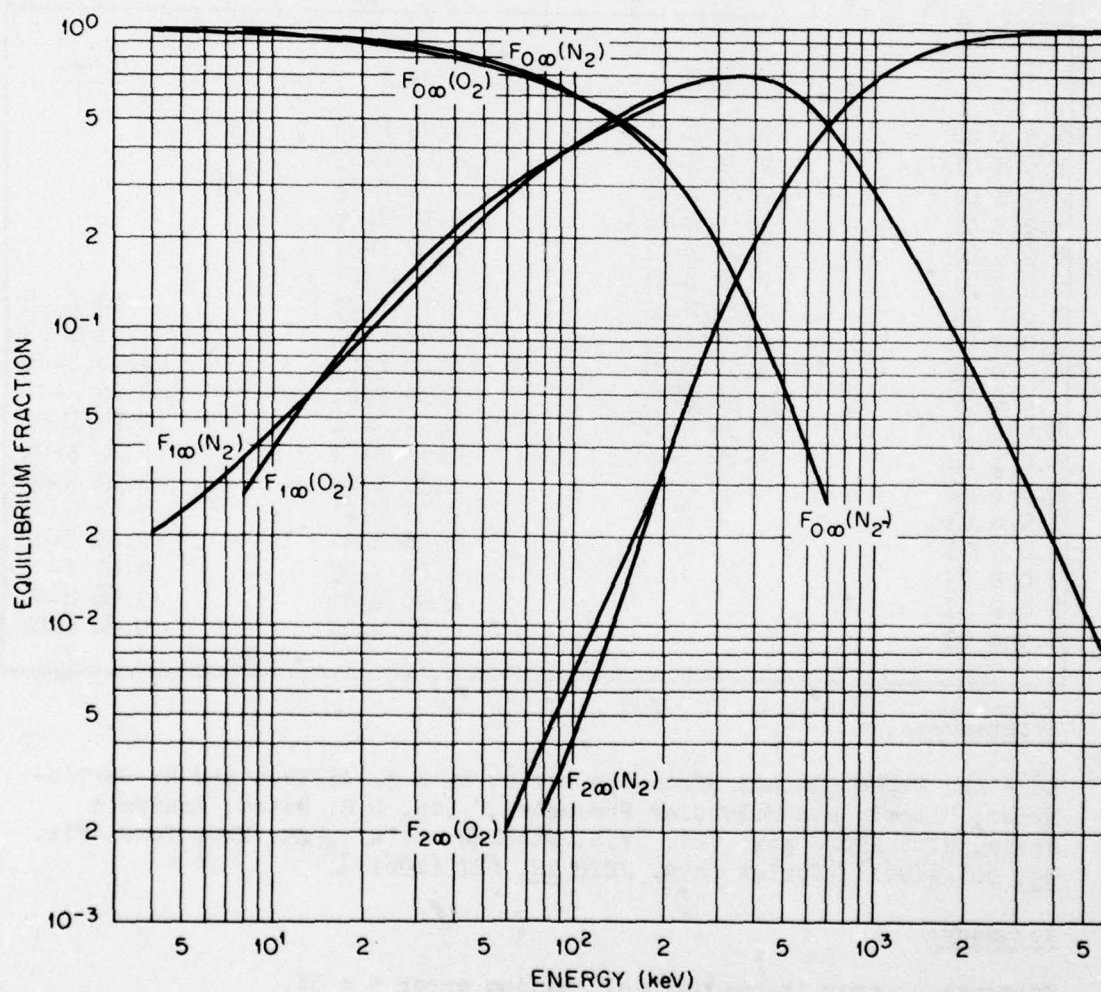
References:

He⁺ + N₂, Experimental: From the review by S.K. Allison and M. Garcia-Munoz, "Atomic and Molecular Processes," (ed. D.R. Bates, Academic Press N.Y. 1962) page 721. V.S. Nikolaev et al., Zh. Eks. Teor. Fiz. 39, 905 (1961) [Soviet Phys. JETP 12, 627 (1961)].

He⁺ + O₂, Experimental: From the review by S.K. Allison and M. Garcia-Munoz, "Atomic and Molecular Processes," (ed. D.R. Bates, Academic Press N.Y. 1962) page 721.

Accuracy:

Systematic error is negligible. Random error < ± 5%.



Graphical Data G-5.8.

Equilibrium Fractions of a Helium Beam in N_2 and O_2 Gases.

Tabular Data G-5.9.

Equilibrium Fractions of a Helium Beam in Ar

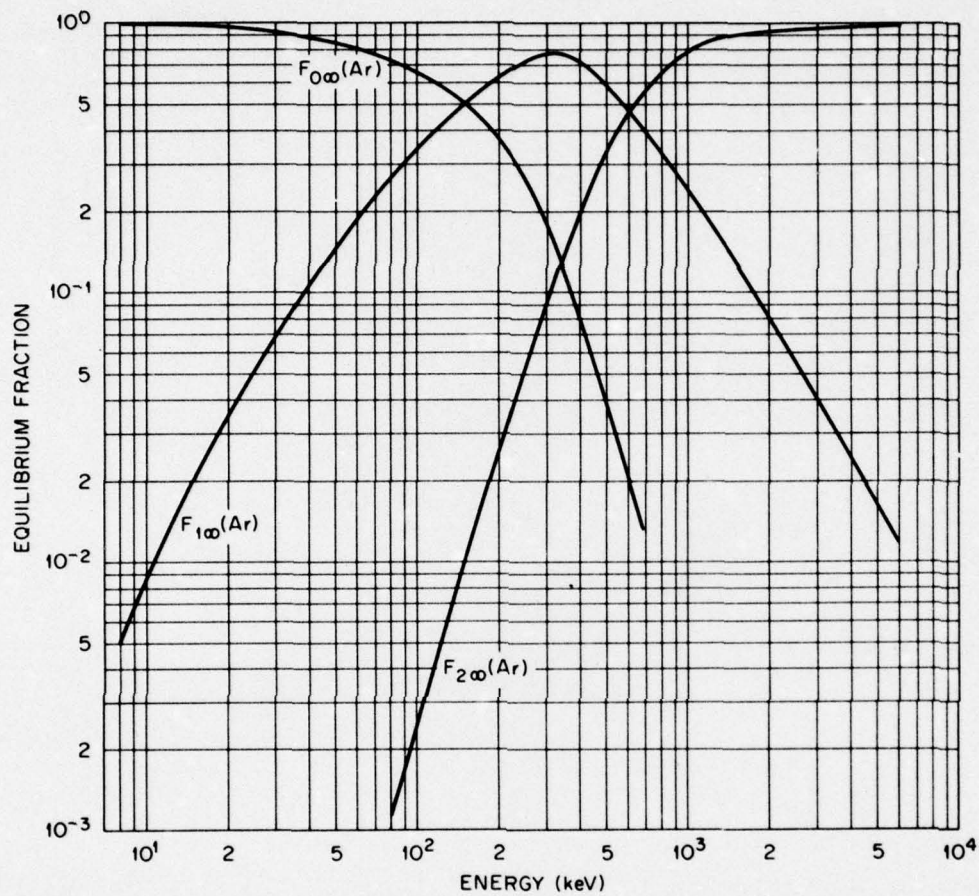
Energy (keV)	Equilibrium Fractions		
	Ar		
	$F_{0\infty}$	$F_{1\infty}$	$F_{2\infty}$
8.0 E 00	9.95 E-01	5.00 E-03	
1.0 E 01	9.91 E-01	8.70 E-03	
2.0 E 01	9.65 E-01	3.51 E-02	
3.0 E 01	9.30 E-01	6.90 E-02	
4.0 E 01	8.91 E-01	1.09 E-01	
6.0 E 01	8.08 E-01	1.92 E-01	
8.0 E 01	7.23 E-01	2.76 E-01	1.10 E-03
1.0 E 02	6.53 E-01	3.44 E-01	2.53 E-03
2.0 E 02	3.53 E-01	6.20 E-01	2.70 E-02
3.0 E 02	1.36 E-01	7.70 E-01	9.39 E-02
4.0 E 02	6.90 E-02	7.14 E-01	2.07 E-01
6.0 E 02	1.90 E-02	4.90 E-01	4.90 E-01
8.0 E 02		3.33 E-01	6.67 E-01
1.0 E 03		2.35 E-01	7.65 E-01
2.0 E 03		8.00 E-02	9.20 E-01
3.0 E 03		4.00 E-02	9.60 E-01
4.0 E 03		2.40 E-02	9.68 E-01
5.0 E 03		1.60 E-02	9.84 E-01

References:

He^+ + Ar, Experimental: From the review by S.K. Allison and M. Garcia-Munoz, "Atomic and Molecular Processes," (ed. D.R. Bates, Academic Press, N.Y. 1962) page 721. V.S. Nikolaev et al., Zh. Eks. Teor. Fiz. 39, 905 (1961) [Soviet Phys. JETP 12, 627 (1961)].

Accuracy:

Systematic error is negligible. Random error $< \pm 5\%$.



Graphical Data G-5.10.
Equilibrium Fractions of a Helium Beam in Ar Gas.

H. PARTICLE AND PHOTON INTERACTIONS WITH SOLIDS

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H-1. SPUTTERING

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Tabular Data H-1.1.

Sputtering Coefficients of He⁺ on C, Be, Al, Si, and Ti

Energy (keV)	Sputtering Coefficients, S (atoms/ion)				
	<u>C</u>	<u>Be</u>	<u>Al</u>	<u>Si</u>	<u>Ti</u>
1.0 E-01	8.0 E-03	4.0 E-02		1.8 E-02	1.0 E-02
2.0 E-01	2.0 E-02	9.3 E-02	5.0 E-03	4.9 E-02	3.7 E-02
3.0 E-01	3.5 E-02	1.4 E-01	8.0 E-03	8.0 E-02	5.2 E-02
6.0 E-01	8.5 E-02	2.5 E-01	2.1 E-02	1.6 E-01	8.0 E-02
1.0 E 00	1.1 E-01	3.5 E-01		2.0 E-01	9.2 E-02
2.0 E 00	1.3 E-01	3.1 E-01		1.6 E-01	9.0 E-02
5.0 E 00	1.2 E-01	1.1 E-01		8.6 E-02	8.2 E-02
7.0 E 00		7.6 E-02		6.4 E-02	9.2 E-02
9.0 E 00	1.0 E-01	5.7 E-02		5.1 E-02	1.0 E-01
2.0 E 01	7.3 E-02		1.7 E-02	2.9 E-02	1.4 E-02
3.0 E 01				2.2 E-02	
5.0 E 01				1.7 E-02	
9.0 E 01				1.6 E-02	

References:

He⁺ → C: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); V. M. Gusev, et al., IAE RR Kurchatov, Moscow, Rpt. No. OLS-7-75.

He⁺ → Be: H. Fetz, H. Oechsner, 6th Int. Conf. Ionization Phenomena Gases, Paris (1963), II, 39; D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Surface Bombardment Studies, Final Rpt. to USAEC, No. 3031 (1966).

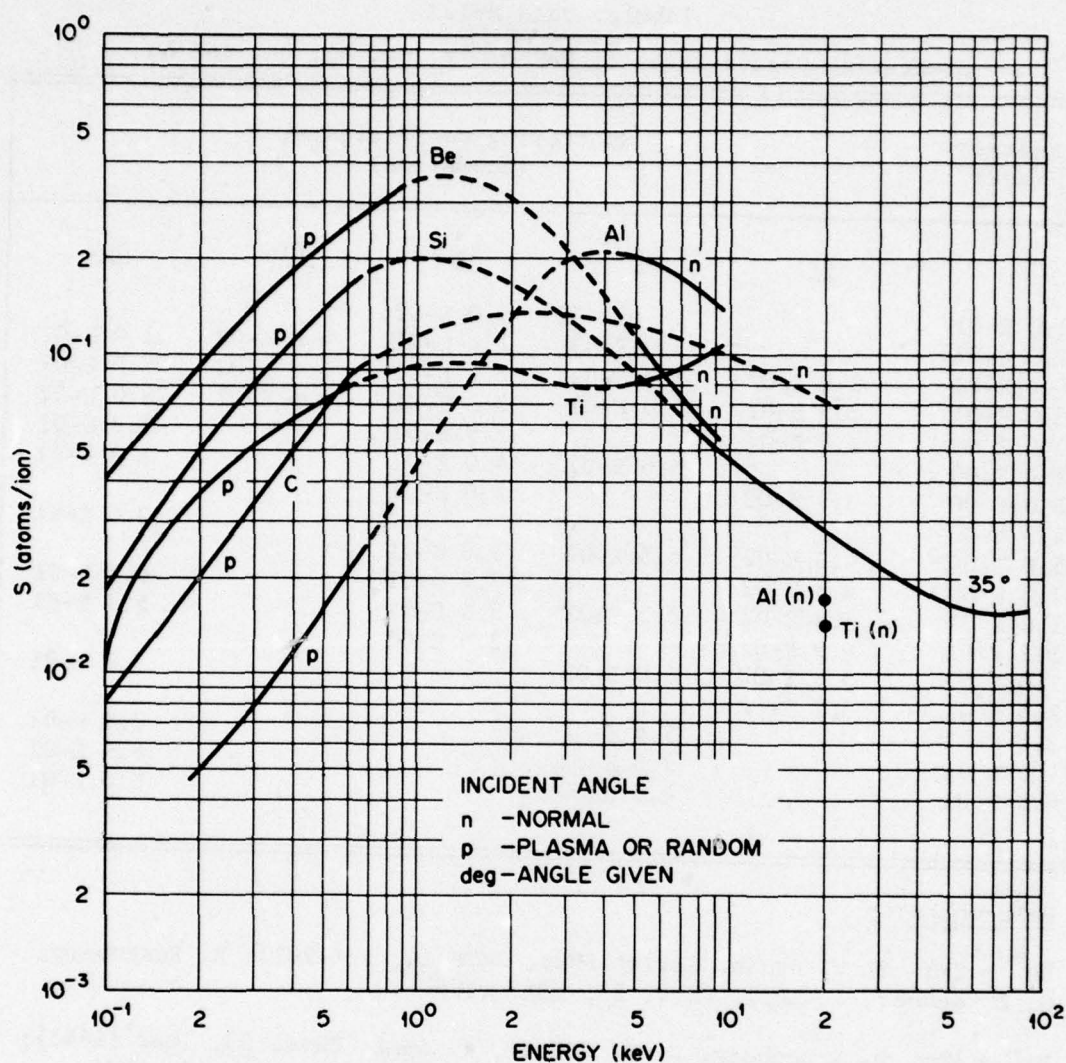
He⁺ → Al: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); O. C. Yonts, ORNL-TM-2692 (1969); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Final Rpt. to USAEC, No. 3031 (1966).

He⁺ → Ti: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Final Rpt. to USAEC No. 3031 (1966); O. C. Yonts, ORNL-TM-2692 (1969).

He⁺ → Si: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, C. KenKnight, D. L. Rosenberg, Planet. Space Sci. 11, 885 (1963); A. van Wijngaarden, B. Miremadi, N. M. A. Finney, Phys. Rev. 185, 490 (1969).

C(45°), Si(35°) data are not corrected for contribution of reflected He⁺ to sputtered ion current (Ref.-Panin; van Wijngaarden, et al.).

Plasma incident data are not corrected for electron emission (Ref.-Rosenberg, et al.).



Sputtering Coefficients of He⁺ on C, Be, Al, Si, and Ti

Graphical Data H-1.2.

Tabular Data H-1.3.

Sputtering Coefficients of He^+ on Zr, Nb, Ag, Pt, and Au

Energy (keV)	Sputtering Coefficients, S (atoms/ion)				
	<u>Zr</u>	<u>Nb</u>	<u>Ag</u>	<u>Pt</u>	<u>Au</u>
1.0 E-01			5.0 E-02		
2.0 E-01		5.0 E-03	1.4 E-01	4.0 E-03	2.0 E-02
4.0 E-01	1.9 E-02	1.7 E-02	2.5 E-01	1.8 E-02	5.0 E-02
6.0 E-01	2.5 E-02	3.0 E-02	3.3 E-01	3.5 E-02	8.0 E-02
1.0 E 00	2.9 E-02		3.9 E-01		1.3 E-01
2.0 E 00		5.6 E-02	4.0 E-01		2.2 E-01
3.0 E 00	3.9 E-02		4.0 E-01		
4.0 E 00					3.6 E-01
5.0 E 00	4.3 E-02	6.5 E-02	3.8 E-01		
7.0 E 00	4.6 E-02		3.7 E-01		5.1 E-01
1.0 E 01	4.8 E-02	6.5 E-02	3.5 E-01		5.9 E-01
1.2 E 01	4.9 E-02		3.4 E-01		
2.0 E 01	5.1 E-02	6.0 E-02			7.0 E-01
2.5 E 01	5.2 E-02				
3.0 E 01		5.6 E-02			7.1 E-01
4.0 E 01		5.3 E-02			6.9 E-01
6.0 E 01		4.8 E-02			6.0 E-01

References:

$\text{He}^+ \rightarrow \text{Zr}$: B. V. Panin, Soviet Phys. JETP 14, 1 (1962); D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962).

$\text{He}^+ \rightarrow \text{Nb}$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); A. J. Summers, N. J. Freeman, N. R. Daly, J. Appl. Phys. 42, 4774 (1971); O. C. Yonts, ORNL-TM-2692 (1969) - Also $\text{He}^+ \rightarrow \text{Nb-Zr}$.

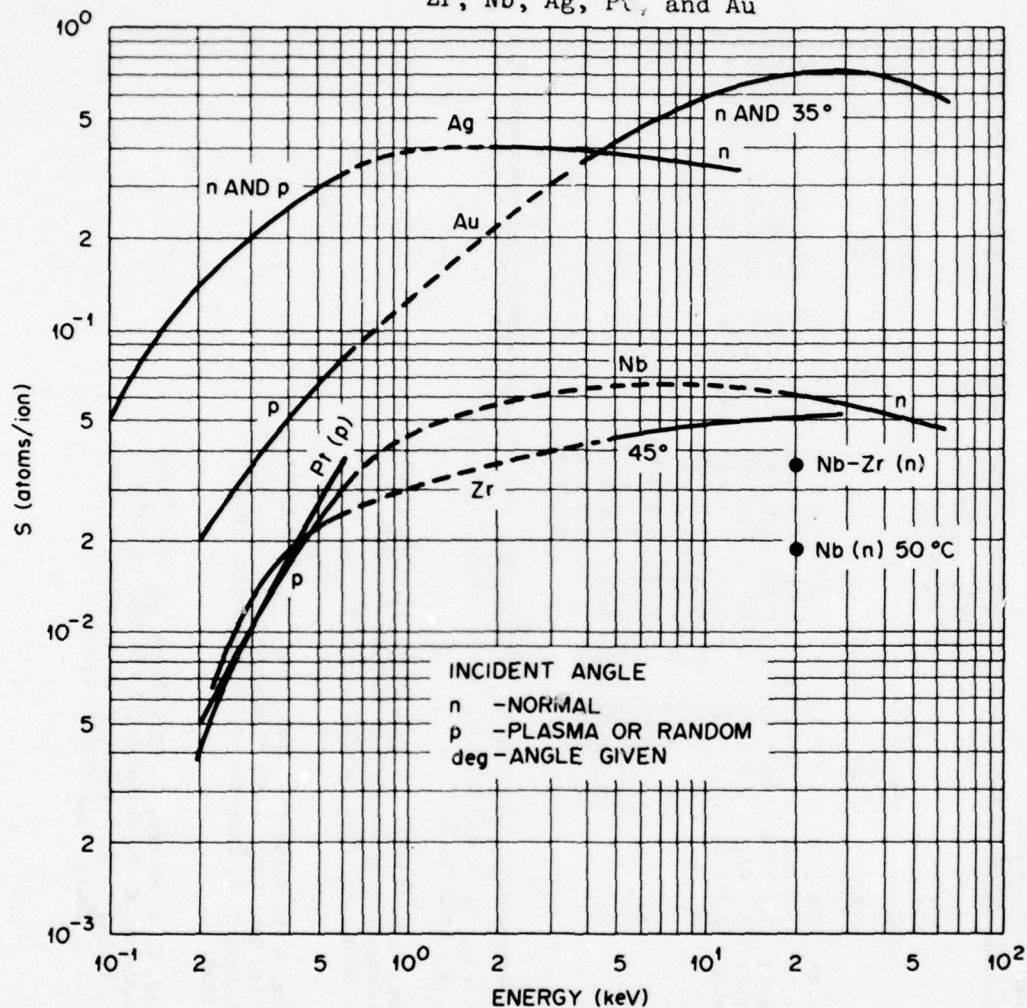
$\text{He}^+ \rightarrow \text{Ag}$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); F. Grönlund, W. J. Moore, J. Chem. Phys. 32, 1540 (1960); M. Koedam, Physica 25, 742 (1959); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Surface Bombardment Studies, Final Rpt. to USAEC, No. 3031 (1966); D. McKeown, H. R. Poppa, M. G. Fox, Molecular Impact Studies, Ann. Rpt. AD-445823 (O.N.R., GDA-DBE64-048), 1964.

$\text{He}^+ \rightarrow \text{Pt}$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962).

$\text{He}^+ \rightarrow \text{Au}$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Final Rpt. to USAEC, No. 3031 (1966); A. van Wijngaarden, E. Reuther, J. N. Bradford, Can. J. Phys 47, 411 (1969).

Sputtering Coefficients of He^+ on

Zr, Nb, Ag, Pt, and Au



Graphical Data H-1.4.

Plasma incident data are not corrected for secondary electron emission (Ref.-Rosenberg, et al.).

Zr (35°) and Au (45°) data not corrected for contribution of reflected He^+ to sputtered ion current (Ref.-Panin; Wijngaarden, et al.).

Tabular Data H-1.5.
Sputtering Coefficients of He^+ on V, Cr, Fe, Ni, Cu, Mo, Ta, and W

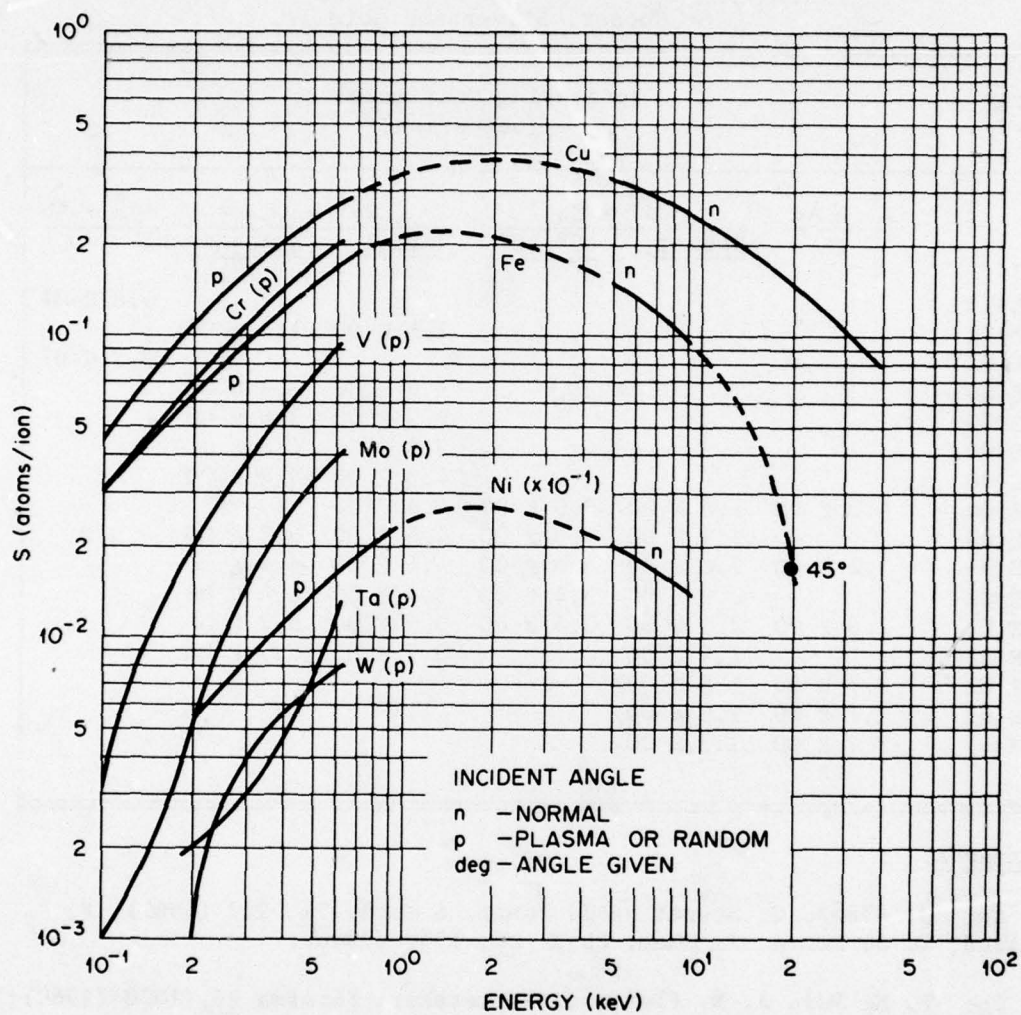
Energy (keV)	Sputtering Coefficients, S (atoms/ion)							
	V	Cr	Fe	Ni	Cu	Mo	Ta	W
1.0 E-01	3.0 E-03	3.0 E-02	3.0 E-02		4.5 E-02	1.0 E-03		
2.0 E-01	2.1 E-02	7.0 E-02	6.3 E-02	5.3 E-02	1.1 E-01	5.0 E-03	2.0 E-03	1.0 E-03
3.0 E-01	3.9 E-02	1.1 E-01	9.2 E-02	8.3 E-02	1.6 E-01	1.4 E-02	3.0 E-03	4.0 E-03
4.0 E-01	5.7 E-02	1.4 E-01	1.2 E-01	1.1 E-01	2.0 E-01	2.4 E-02	4.5 E-03	5.6 E-03
6.0 E-01	9.0 E-02	2.0 E-01	1.6 E-01	1.6 E-01	2.7 E-01	4.0 E-02	1.2 E-02	8.0 E-03
9.0 E-01			2.1 E-01	2.3 E-01	3.3 E-01			
2.0 E 00			2.1 E-01	2.7 E-01	3.8 E-01			
5.0 E 00			1.5 E-01	2.0 E-01	3.3 E-01			
7.0 E 00			1.2 E-01	1.7 E-01	2.9 E-01			
9.0 E 00			9.6 E-02	1.4 E-01	2.6 E-01			
2.0 E 01			1.7 E-02		1.5 E-01			
3.9 E 01					8.0 E-02			

$\text{He}^+ \rightarrow \text{V}$, $\text{He}^+ \rightarrow \text{Cr}$, $\text{He}^+ \rightarrow \text{Mo}$, $\text{He}^+ \rightarrow \text{Ta}$, $\text{He}^+ \rightarrow \text{W}$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962).

$\text{He}^+ \rightarrow \text{Fe}$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Surface Bombardment Studies, Final Rpt. to USAEC, No. 3031 (1966); D. Heymann, J. Geophys. Res. 69, 1941 (1964).

$\text{He}^+ \rightarrow \text{Ni}$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); H. Fetz, H. Oechsner, 6th Int. Conf. Ionization Phenomena Gases, p. 39, Paris (1963); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Final Rpt. to USAEC, No. 3031 (1966).

$\text{He}^+ \rightarrow \text{Cu}$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Final Rpt. to USAEC, No. 3031 (1966); O. C. Yonts, C. E. Normand, D. E. Harrison, J. Appl. Phys. 31, 447 (1960); O. C. Yonts, ORNL-TM-2692 (1969).



Graphical Data H-1.6.
 Sputtering Coefficients of He^+ on V,
 Cr, Fe, Ni, Cu, Mo, Ta, and W

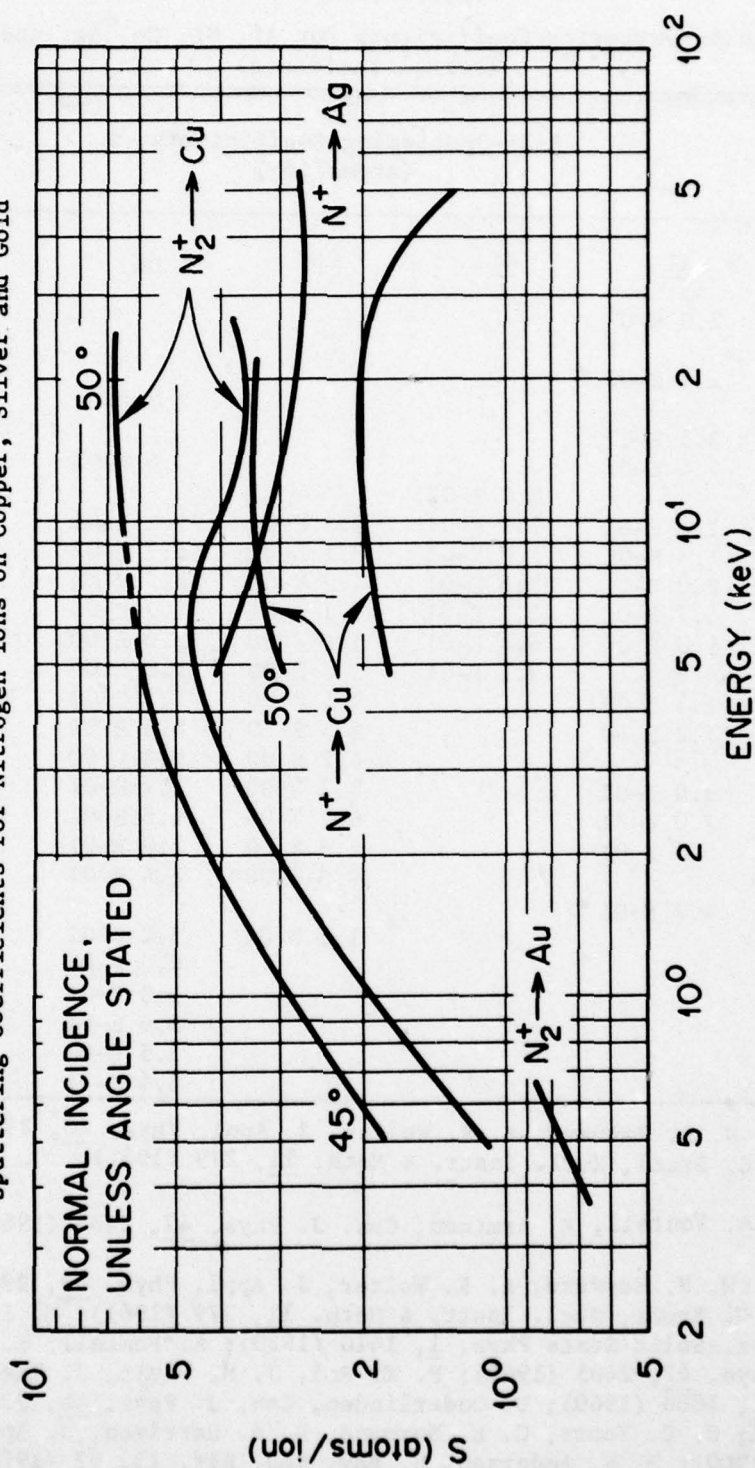
Tabular Data H-1.7.
Sputtering Coefficients for Nitrogen Ions
on Copper, Silver and Gold

Energy (keV)	Sputtering Coefficients, S (atoms/ion)					
	<u>N⁺ + Ag</u>	<u>N⁺ + Cu</u>		<u>N₂⁺ + Cu</u>		<u>N₂⁺ + Au</u>
		<u>Normal</u>	<u>45°-50°</u>	<u>Normal</u>	<u>45°-50°</u>	
4.0 E-01						6.8 E-01
5.0 E-01				1.1 E 00	1.8 E 00	
6.0 E-01						8.3 E-01
1.0 E 00				1.9 E 00	2.8 E 00	
1.5 E 00				2.5 E 00	3.6 E 00	
2.5 E 00				3.4 E 00	4.8 E 00	
4.0 E 00				4.3 E 00	5.7 E 00	
5.0 E 00	4.0 E 00	1.8 E 00	3.0 E 00	4.6 E 00		
7.0 E 00		1.9 E 00	3.3 E 00	4.6 E 00	6.2 E 00	
1.0 E 01	3.2 E 00	2.0 E 00	3.4 E 00	4.1 E 00	6.4 E 00	
1.5 E 01		2.0 E 00	3.4 E 00	3.6 E 00	6.6 E 00	
2.0 E 01	2.8 E 00	2.0 E 00	3.4 E 00	3.6 E 00	6.7 E 00	
2.5 E 01		1.9 E 00		3.7 E 00	6.7 E 00	
3.0 E 01	2.7 E 00	1.8 E 00				
4.0 E 01	2.7 E 00	1.6 E 00				
5.0 E 01	2.7 E 00	1.3 E 00				

References:

- $N^+ \rightarrow Ag$: O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 257 (1961); F. Grönlund, W. J. Moore, J. Chem. Phys. 32, 1540 (1960).
- $N^+ \rightarrow Cu$: P. K. Rol, J. M. Fluit, J. Kistemaker, Physica 26, 1000 (1960); O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 257 (1961).
- $N_2^+ \rightarrow Cu$: P. K. Rol, J. M. Fluit, J. Kistemaker, Physica 26, 1000 (1960); T. W. Snouse, Rpt. NASA TN D-2235 (1964).
- $N_2^+ \rightarrow Au$: J. S. Colligon, C. M. Hicks, A. P. Neokleous, Rad. Eff. 18, 119 (1973).

Sputtering Coefficients for Nitrogen Ions on Copper, Silver and Gold



Graphical Data H-1.8.

Tabular Data H-1.9.
Self-Sputtering Coefficients for Al, Ni, Cu, Ag, and Au
(normal incidence)

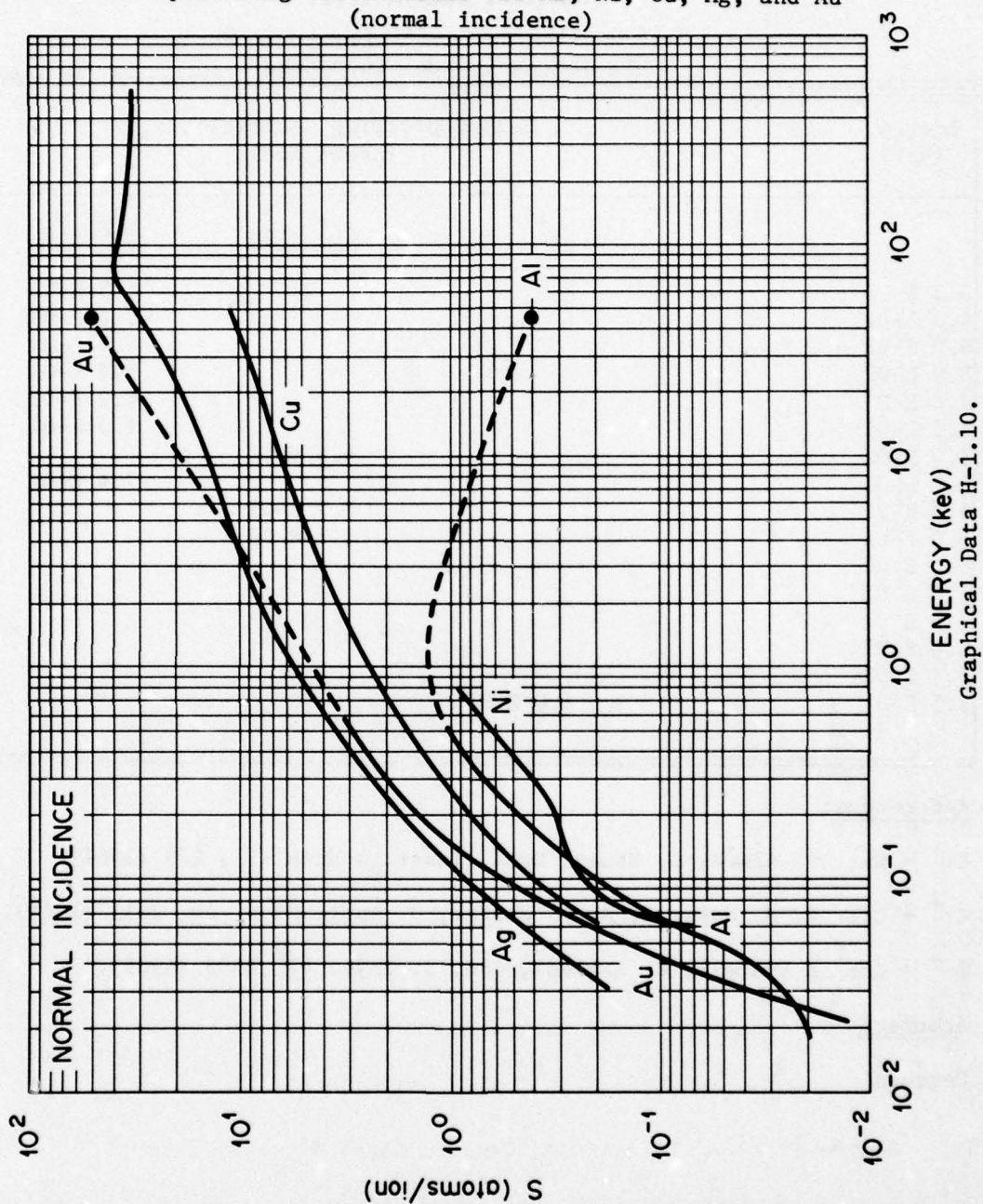
Energy (keV)	Self-Sputtering Coefficients, S (atoms/ion)				
	<u>Al</u>	<u>Ni</u>	<u>Cu</u>	<u>Ag</u>	<u>Au</u>
2.0 E-02	2.0 E-02				
2.2 E-02					1.4 E-02
3.0 E-02	2.5 E-02				3.9 E-02
3.5 E-02				2.2 E-01	
4.0 E-02	3.5 E-02				8.3 E-02
5.0 E-02	5.6 E-02			3.6 E-01	1.4 E-01
6.0 E-02		8.0 E-02			2.2 E-01
6.5 E-02	1.0 E-01	1.1 E-01	2.2 E-01	5.1 E-01	
8.0 E-02	1.4 E-01	1.8 E-01	3.1 E-01	6.7 E-01	3.9 E-01
1.0 E-01	2.0 E-01	2.3 E-01	4.0 E-01	8.7 E-01	5.9 E-01
2.0 E-01	4.7 E-01	3.1 E-01	8.1 E-01	1.7 E 00	1.4 E 00
5.0 E-01	1.0 E 00	6.4 E-01	1.6 E 00	3.6 E 00	2.9 E 00
8.0 E-01		9.1 E-01	2.2 E 00	5.0 E 00	
1.0 E 00	1.3 E 00		2.5 E 00	5.7 E 00	4.6 E 00
2.0 E 00	1.2 E 00		3.5 E 00	8.3 E 00	7.0 E 00
3.0 E 00			4.2 E 00	9.8 E 00	
5.0 E 00	9.0 E-01		5.2 E 00	1.1 E-01	1.3 E-01
1.0 E 01	7.0 E-01		6.7 E 00	1.5 E-01	2.0 E-01
2.0 E 01	5.5 E-01		8.3 E 00	2.0 E-01	3.1 E-01
3.0 E 01			9.3 E 00	2.4 E-01	
4.5 E 01	4.2 E-01				5.2 E-01
5.0 E 01			1.1 E 01	3.2 E-01	
7.0 E 01				4.0 E-01	
1.0 E 02				3.9 E-01	
2.0 E 02				3.6 E-01	
3.0 E 02				3.5 E-01	
5.0 E 02				3.4 E-01	

$\text{Al}^+ \rightarrow \text{Al}$: W. H. Hayward, A. R. Wolter, J. Appl. Phys. 40, 2911 (1969);
O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961).

$\text{Ni}^+ \rightarrow \text{Ni}$: A. Fontell, E. Arminen, Can. J. Phys. 47, 2405 (1969).

$\text{Cu}^+ \rightarrow \text{Cu}$: W. H. Hayward, A. R. Wolter, J. Appl. Phys. 40, 2911 (1969);
O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961); M. I. Guseva,
Soviet Phys.-Solid State Phys. 1, 1410 (1959); A. Fontell, E. Arminen,
Can. J. Phys. 47, 2405 (1969); P. K. Rol, J. M. Fluit, J. Kistemaker,
Physica 26, 1000 (1960); D. Onderlinden, Can. J. Phys. 46, 739 (1968) -
Cu crystal; O. C. Yonts, C. E. Normand, D. E. Harrison, J. Appl. Phys.
31, 447 (1960); H. H. Andersen, H. Bay, Rad. Eff. 13, 67 (1972).

Self-Sputtering Coefficients for Al, Ni, Cu, Ag, and Au
(normal incidence)



$\text{Ag}^+ \rightarrow \text{Ag}$: W. H. Hayward, A. R. Wolter, J. Appl. Phys. 40, 2911 (1969);
O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961); M. I. Guseva,
Soviet Phys.-Solid State Phys. 1, 1410 (1959); H. H. Andersen, H. L.
Bay, Rad. Eff. 19, 139 (1973).

$\text{Au}^+ \rightarrow \text{Au}$: W. H. Hayward, A. R. Wolter, J. Appl. Phys. 40, 2911 (1969);
O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961).

Graphical Data H-1.11.
Self-Sputtering Coefficients for Si,
Cr, and Zn (normal incidence)

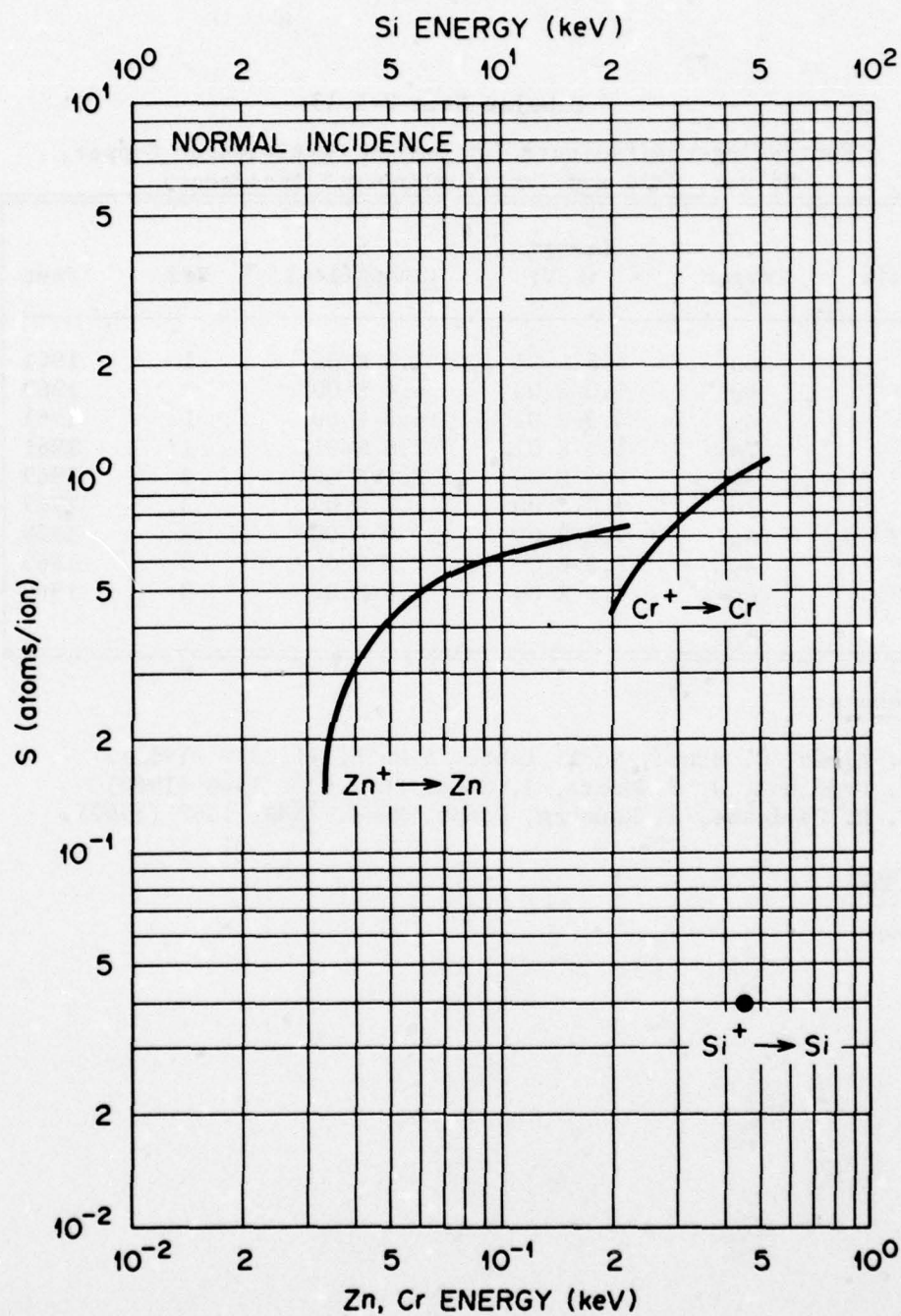
Energy (keV)	Self-Sputtering Coefficients, S (atoms/ion)		
	<u>Si⁺ → Si</u>	<u>Cr⁺ → Cr</u>	<u>Zn⁺ → Zn</u>
3.3 E-02			1.5 E-01
4.0 E-02			3.1 E-01
6.0 E-02			5.0 E-01
8.0 E-02			5.8 E-01
1.0 E-01			6.2 E-01
1.5 E-01			7.0 E-01
2.0 E-01		4.5 E-01	
2.1 E-01			7.4 E-01
3.0 E-01		7.7 E-01	
5.0 E-01		1.1 E 00	
5.0 E 00			
1.0 E 01			
1.5 E 01			
2.0 E 01			
2.1 E 01			
4.5 E 01	4.0 E-02		

References:

- Si⁺ → Si: O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961).
 Cr⁺ → Cr: W. H. Hayward, A. R. Wolter, J. Appl. Phys. 40, 2911 (1969).
 Zn⁺ → Zn: A Fontell, E. Arminen, Can. J. Phys. 47, 2405 (1969).

Accuracy:

Unknown



Graphical Data H-1.12.

Self-Sputtering Coefficients for Si, Cr, and Zn
(normal incidence)

Tabular Data H-1.13.

Sputtering Coefficients for Oxygen Particles on Copper,
Silver, Gold and Tantalum (normal incidence)

Particle	Target	Energy (keV)	S (atoms/ion)	Ref.	Year
O ⁺	Cu	4.5 E 01	1.0 E 00	1	1961
O ⁺	Ag	5.0 E 00	4.4 E 00	2	1960
O ⁺	Ag	4.5 E 01	4.8 E 00	1	1961
O ⁺	Ta	4.5 E 01	2.0 E -01	1	1961
O ⁰	Ag	9.0 E 00	2.6 E 00	3	1969
O ⁰	Au	9.0 E 00	1.7 E 00	3	1969
O ₂ ⁰	Ag	9.0 E 00	6.0 E 00	3	1969
O ₂ ⁰	Au	9.0 E 00	2.8 E 00	3	1969
O ₃ ⁰	Ag	9.0 E 00	7.6 E 00	3	1969

References:

1. O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961).
2. F. Grönlund, W. J. Moore, J. Chem. Phys. 32, 1540 (1960).
3. F. M. Devienne, A. Roustan, Compt. Rend. 268B, 1362 (1969).

Accuracy:

Unknown

Tabular Data H-1.14.
Self-Sputtering of V, Fe, Zr, Nb, Mo, Ta,
and W⁺ at 45 keV (normal incidence)

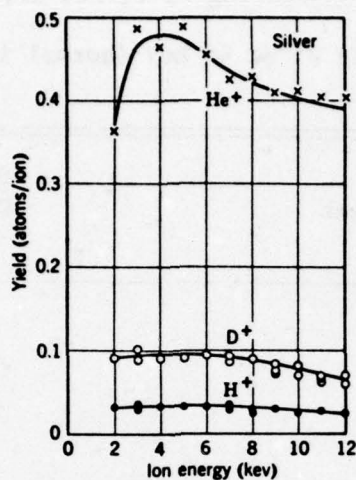
Element	Self-Sputtering Coefficient, s (atoms/ion)
V	7.6 E-01
Fe	2.8 E 00
Zr	1.2 E 00
Nb	1.3 E 00
Mo	2.1 E 00
Ta	3.1 E 00
W	4.8 E 00

Reference:

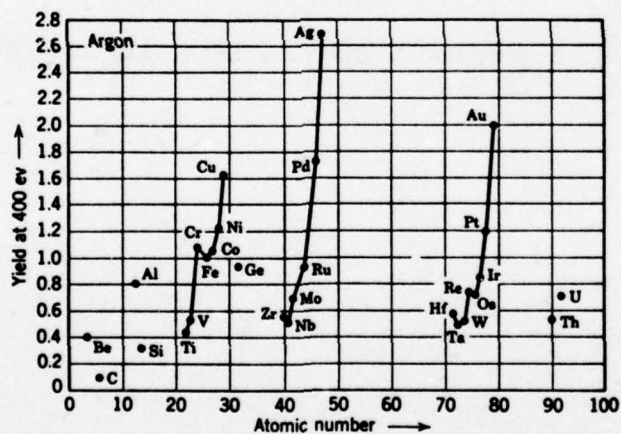
O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961).

Accuracy:

Unknown



Sputtering yields of silver for H^+ , D^+ , and He^+ ions. F. Grønlund and W. J. Moore, *J. Chem. Phys.* 32, 1540 (1960).



Sputtering yields for 400-eV argon ions on 28 elements plotted against the atomic number of the element. N. Laegreid and G. K. Wehner, *J. Appl. Phys.* 32, 365 (1961).

Graphical Data H-1.15.

H-2. SECONDARY ELECTRON EMISSION BY ELECTRON IMPACT

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Tabular Data H-2.1.

Emission of Secondary Electrons by Electron Impact
on a Steel Surface
(Electrons Incident Normally on Surface)
e on Steel

Energy Impact (keV)	Secondary Electron Emission Coefficient δ Electrons/Electron
4.0 E 01	3.08 E-01
6.0 E 01	2.14 E-01
8.0 E 01	1.60 E-01
1.0 E 02	1.34 E-01
1.5 E 02	1.04 E-01
2.0 E 02	8.80 E-02

Reference:

J.G. Trump and R.J. Van de Graaff, Phys. Rev. 75, 44 (1948).

Accuracy:

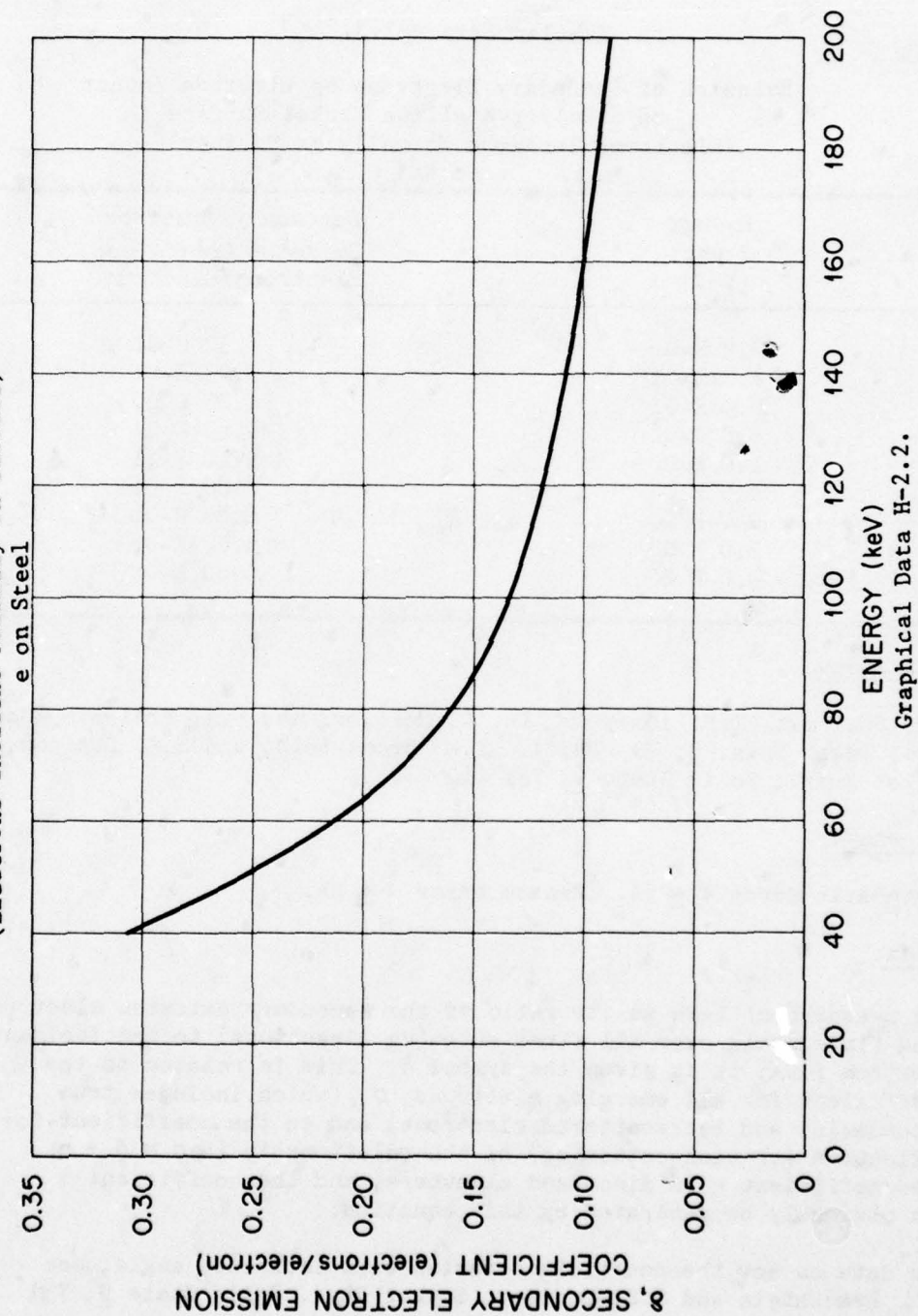
Unknown

Notes:

The data of Trump and Van de Graaff are for total flux of electrons (true secondaries plus backscattered electrons) and for the flux with energies over 800 eV (presumably representing backscattered electrons). We present here the difference between the two which should represent the true secondary emission alone.

The type of steel used in this work was not specified.

Emission of Secondary Electrons by Electron Impact on a Steel Surface
(Electrons Incident Normally on Surface)



Tabular Data H-2.3.

Emission of Secondary Electrons by Electron Impact
on a Polycrystalline Nickel Surface
(Electrons Incident Normally on Surface)
e on Ni

Energy Impact (keV)	Secondary Electron Emission Coefficient δ Electrons/Electron
2.0 E-01	8.32 E-01
4.0 E-01	9.93 E-01
6.0 E-01	1.00 E 00
8.0 E-01	9.60 E-01
1.0 E 00	9.10 E-01
1.5 E 00	7.80 E-01
2.0 E 00	6.86 E-01
3.0 E 00	5.52 E-01
4.0 E 00	4.60 E-01

References:

A.R. Shul'man, I.R. Zakiyova, Iu. A. Morozov, and S.A. Freidman, Soviet Phys. Tech. Phys. 3, 79 (1958). I.M. Bronshtein, and S.S. Denisov, Soviet Phys., Solid State 9, 731 (1967).

Accuracy:

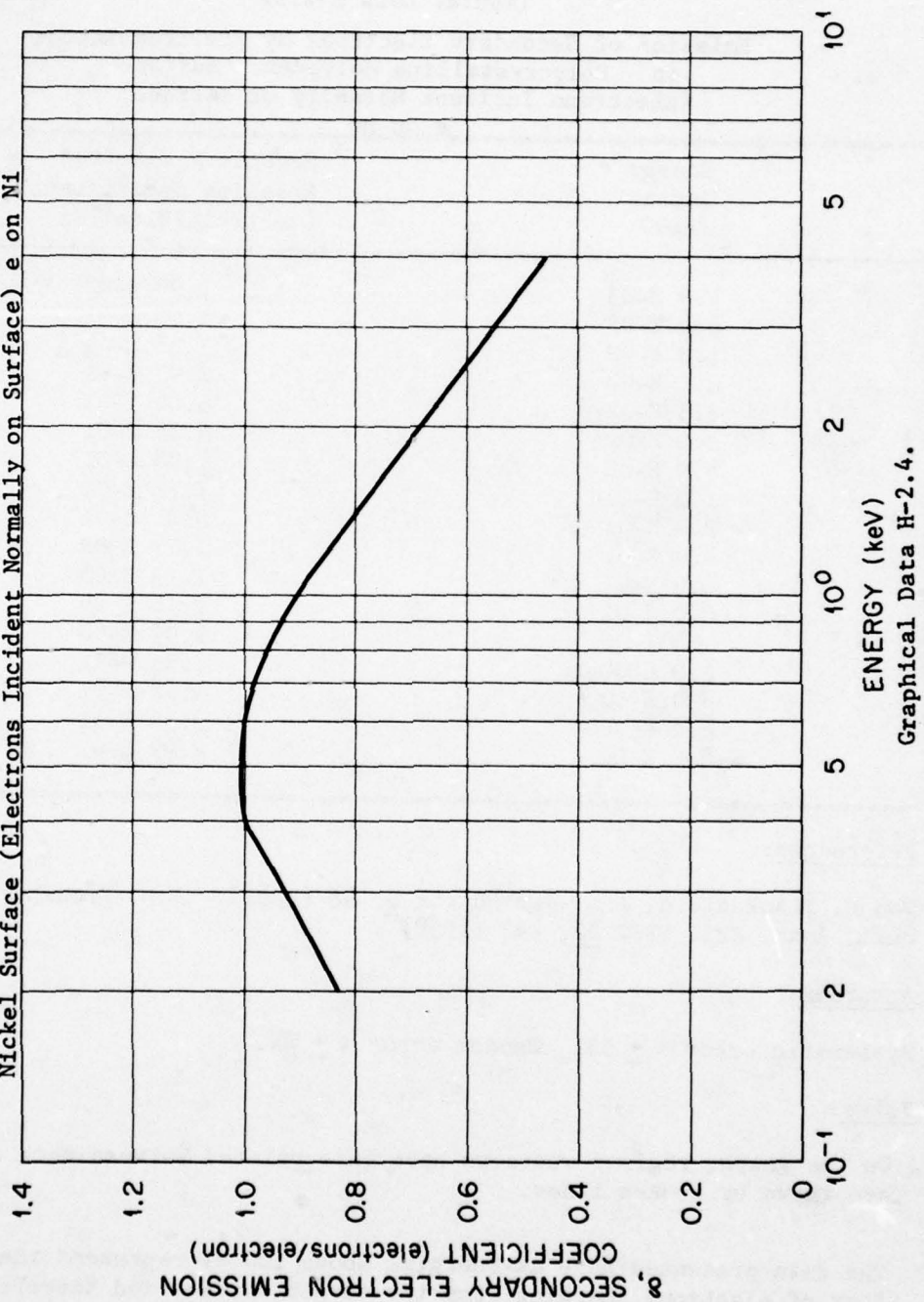
Systematic error $< \pm 5\%$. Random error $< \pm 2\%$.

Notes:

The measurement here is the ratio of the secondary emission electron flux (integrated over all final outgoing directions) to the incident electron flux; it is given the symbol δ . This is related to the coefficient for all emerging electrons, σ , (which includes true secondaries and backscattered electrons) and to the coefficient for reflection (or backscattering) η ; the relationship is $\sigma = \delta + \eta$. The coefficient η is discussed elsewhere, and the coefficient σ can obviously be generated by this equation.

For data on how the coefficient varies with incidence angle, see I.M. Bronshtein and S.S. Denisov, Soviet Phys. Solid State 9, 731 (1967).

Emission of Secondary Electrons by Electron Impact on a Polycrystalline Nickel Surface (Electrons Incident Normally on Surface) e on Ni



Graphical Data H-2.4.

Tabular Data H-2.5.

Emission of Secondary Electrons by Electron Impact
on Polycrystalline Molybdenum Surface
(Electrons Incident Normally on Surface)
e on Mo

Energy Impact (keV)	Secondary Electron Emission Coefficient δ Electrons/Electron
4.0 E-03	1.90 E-02
8.0 E-03	1.00 E-01
1.0 E-02	1.38 E-01
2.0 E-02	2.93 E-01
2.5 E-02	3.60 E-01
3.0 E-02	4.15 E-01
4.0 E-02	4.98 E-01
1.0 E-01	7.72 E-01
2.0 E-01	9.81 E-01
4.0 E-01	1.27 E 00
6.0 E-01	1.23 E 00
8.0 E-01	1.16 E 00
1.0 E 00	1.09 E 00
2.0 E 00	7.55 E-01
4.0 E 00	4.52 E-01
6.0 E 00	3.36 E-01
8.0 E 00	2.99 E-01

References:

Von G. Blankenfeld, Ann. der Physik 9, 48 (1951). I.M. Bronshtein, Bull. Acad. Sci. USSR 22, 442 (1958).

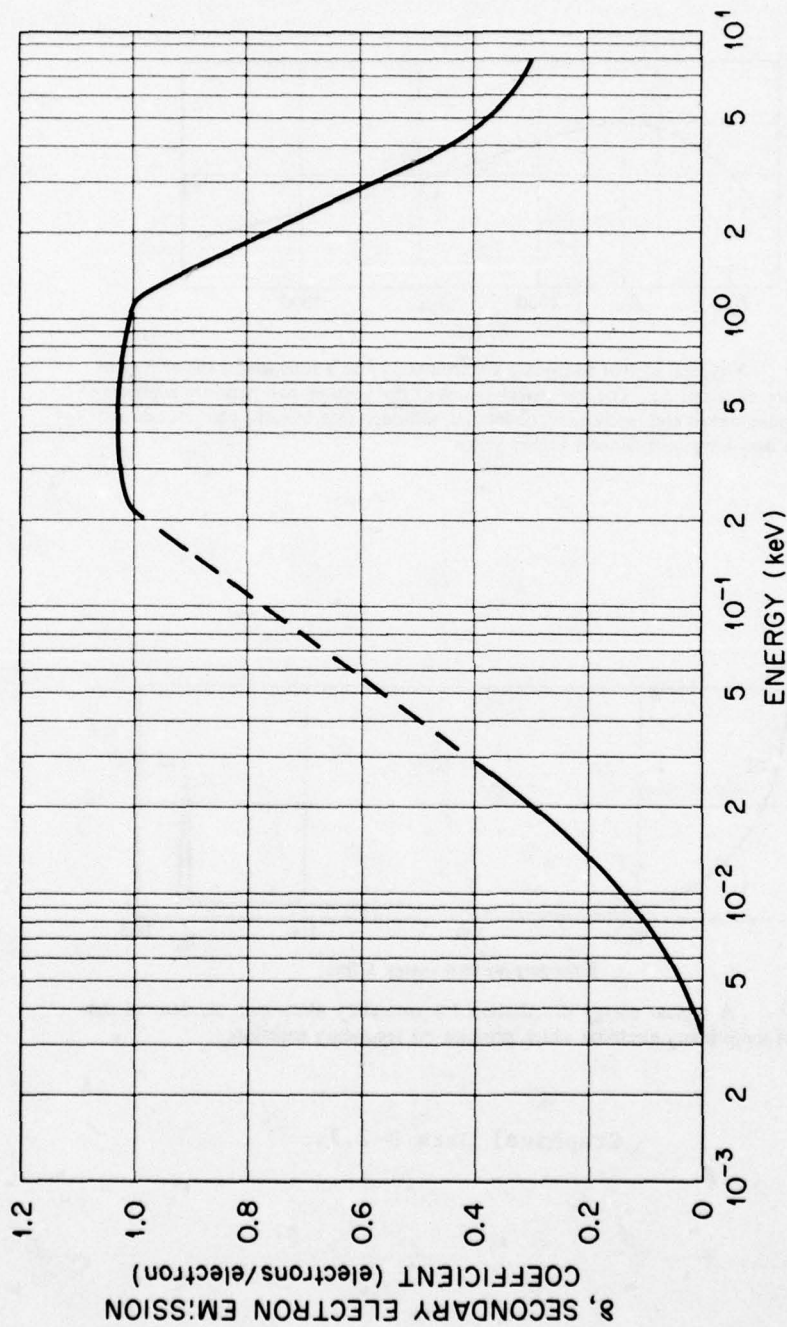
Accuracy:

Systematic error < \pm 5%. Random error < \pm 2%.

Notes:

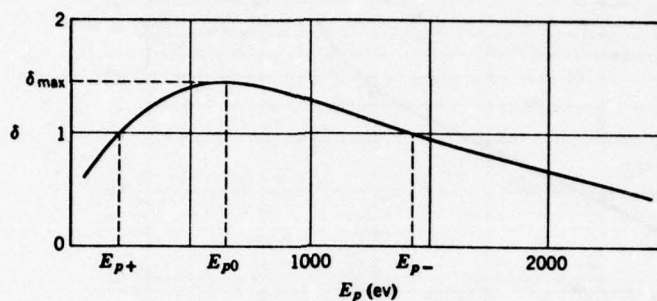
On the graph, regions where we have interpolated between data sets are shown by broken lines.

The data presented here at energies above 100 eV represent the total flux of electrons emerging from the target surface and therefore is the sum of the true secondary emission and the backscattered electron flux. There appear to be no reliable measurements of the true secondary emission alone.

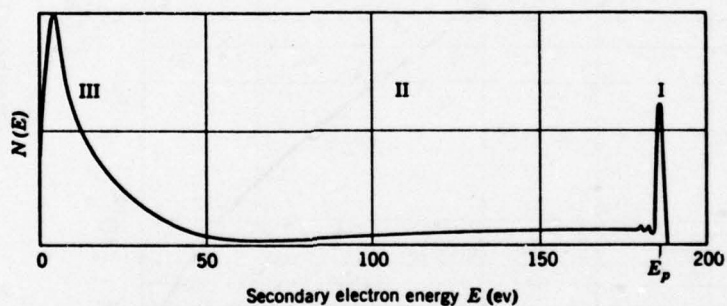


Graphical Data H-2.6.

Emission of Secondary Electrons by Electron Impact on a Polycrystalline Molybdenum Surface
(Electrons Incident Normally on Surface)
e on Mo



(a) A typical plot of secondary electron yield δ as a function of the energy of the primary electrons E_p . The numerical values of the yield shown here are representative of pure metals and many semiconductors, although intermetallic compounds and insulators may have considerably higher yields.



(b) A typical energy distribution for secondary electrons; E_p denotes the energy of the primary electrons which produce the secondary emission.

Graphical Data H-2.7.

Tabular Data H-2.8.

Values of the peak secondary electron yields δ_{\max} and the primary electron energies E_{p0} at which they occur for different metals. The electron energies E_{p+} and E_{p-} for which the yields equal unity are also indicated. This table is taken from the review by Hachenberg and Brauer.*

Atomic Number	Chemical Symbol	δ_{\max}	E_{p0}	E_{p+}	E_{p-}
3	Li	0.5	85	-	-
4	Be	0.5	200	-	-
11	Na	0.82	300	-	-
12	Mg	0.95	300	-	-
13	Al	0.95	300	-	-
19	K	0.7	200	-	-
22	Ti	0.9	280	-	-
26	Fe	1.3	(400)	120	1400
27	Co	1.2	(500)	200	-
28	Ni	1.35	550	150	1750
29	Cu	1.3	600	200	1500
37	Rb	0.9	350	-	-
40	Zr	1.1	350	175	(600)
41	Cb	1.2	375	175	1100
42	Mo	1.25	375	150	1300
46	Pd	>1.3	>250	120	-
47	Ag	1.47	800	150	>2000
48	Cd	1.14	450	300	700
50	Sn	1.35	500	-	-
51	Sb	1.3	600	250	2000
55	Cs	0.72	400	-	-
56	Ba	0.82	400	-	-
73	Ta	1.3	600	250	>2000
74	W	1.35	650	250	1500
78	Pt	1.5	750	350	3000
79	Au	1.45	800	150	>2000
80	Hg	1.3	600	350	>1200
81	Tl	1.7	650	70	>1500
82	Pb	1.1	500	250	1000
83	Bi	1.5	900	80	>2000
90	Ta	1.1	800	-	-

* O. Hachenberg and W. Brauer, "Secondary Electron Emission from Solids," in *Advances in Electronics and Electron Physics*, Vol. XI, 413-499 (1959), Academic New York.

Tabular Data H-2.9.

Maximum secondary electron yields from semiconductors and insulators under electron bombardment. These data are taken from the review by Hachenberg and Brauer.*

Group	Substance	δ_{\max}	E_{p0}
Semiconductive elements	Ge (single crystal)	1.2-1.4	400
	Si (single crystal)	1.1	250
	Se (amorphous)	1.3	400
	Se (crystal)	1.35-1.40	400
	C (diamond)	2.8	750
	C (graphite)	1	250
	B	1.2	150
Semiconductive compounds	Cu ₂ O	1.19-1.25	400
	PbS	1.2	500
	MoS ₂	1.10	
	MoO ₂	1.09-1.33	
	Ag ₂ O	0.98-1.18	
	ZnS	1.8	350
Intermetallic compounds	SbCs ₃	5-6.4	700
	SbCs	1.9	550
	BiCs ₃	6-7	1000
	Bi ₂ Cs	1.9	1000
	GeCs	7	700
Insulators	LiF (evaporated layer)	5.6	
	NaF (layer)	5.7	
	NaCl (layer)	6-6.8	600
	NaCl (single crystal)	14	1200
	NaBr (layer)	6.2-6.5	
	NaBr (single crystal)	24	1800
	NaI (layer)	5.5	
	KCl (layer)	7.5	1200
	KCl (single crystal)	12	
	KI (layer)	5.5	
	KI (single crystal)	10.5	1600
	RbCl (layer)	5.8	
	KBr (single crystal)	12-14.7	1800
	BeO	3.4	2000
	MgO (layer)	4	400
	MgO (single crystal)	23	1200
	BaO (layer)	4.8	400
	BaO—SrO (layer)	5-12	1400
	Al ₂ O ₃ (layer)	1.5-9	350-1300
	SiO ₂ (quartz)	2.4	400
Glasses	Mica	2.4	300-384
	Technical glasses	2-3	300-420
	Pyrex	2.3	340-400
	Quartz-glass	2.9	420

* O. Hachenberg and W. Brauer, "Secondary Electron Emission from Solids," in *Advances in Electronics and Electron Physics*, Vol. XI, 413-499 (1959), Academic New York.

H-3. SECONDARY ELECTRON EMISSION BY ION IMPACT

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Tabular Data H-3.1.

Secondary Electron Emission by Impact of Ions
on a Polycrystalline Nickel Target:

H^+ , H_2^+ , H_3^+ , He^+ , on Ni
(Projectiles Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion			
	H^+	H_2^+	H_3^+	He^+
1.0 E 00				1.70 E-01
2.0 E 00				2.30 E-01
4.0 E 00				3.50 E-01
6.0 E 00				4.40 E-01
8.0 E 00				5.50 E-01
1.0 E 01				6.50 E-01
1.5 E 01				8.15 E-01
2.0 E 01	9.60 E-01	1.20 E 00	1.38 E 00	9.60 E-01
4.0 E 01	1.25 E 00	1.60 E 00	1.81 E 00	1.30 E 00
6.0 E 01	1.45 E 00	1.97 E 00	2.25 E 00	
8.0 E 01	1.52 E 00	2.32 E 00	2.68 E 00	
1.0 E 02	1.58 E 00	2.65 E 00	2.97 E 00	
1.2 E 02	1.60 E 00	2.83 E 00	3.24 E 00	
1.3 E 02	1.60 E 00	2.95 E 00	3.30 E 00	

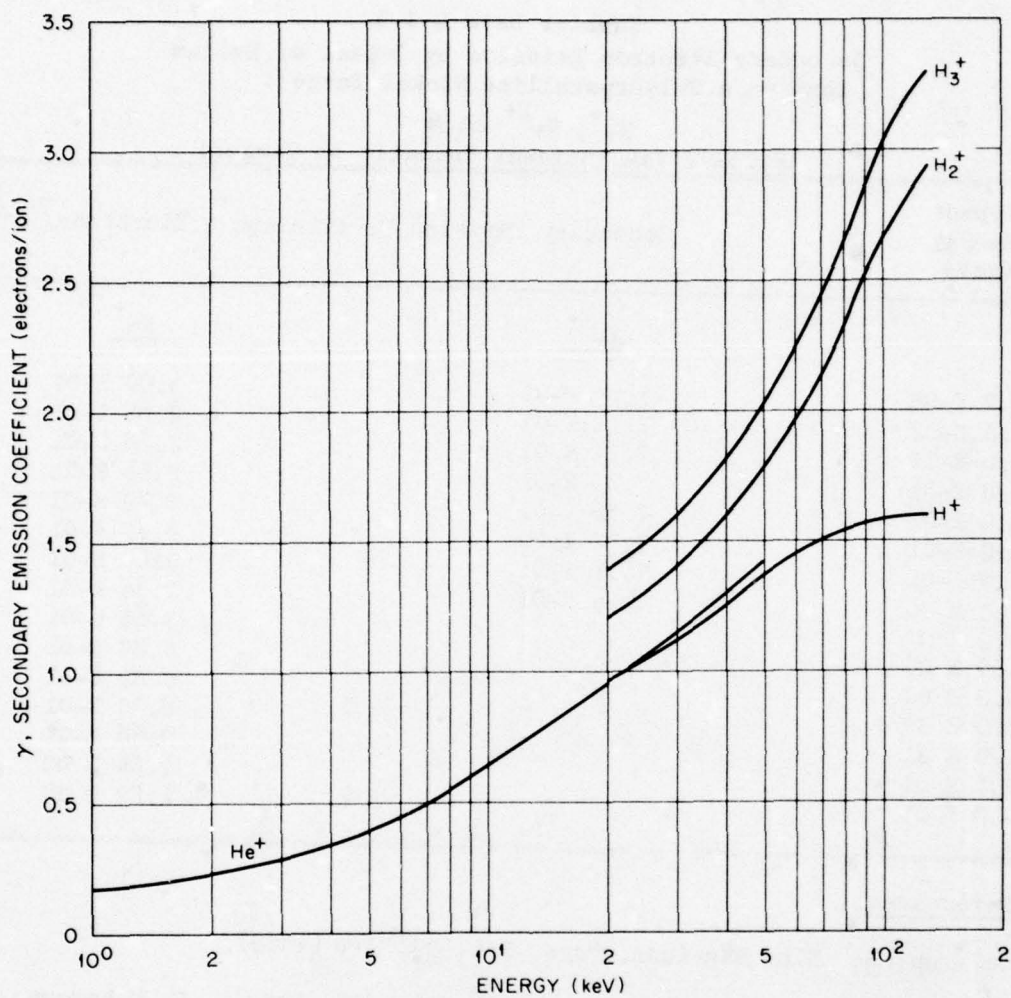
References:

H^+ , H_2^+ , H_3^+ on Ni: L.N. Large, W.S. Whitlock, Proc. Phys. Soc. 79, 148 (1962).

He^+ on Ni: V.A. Arifov, R.R. Rakhimov, and O.V. Khozinskii, Bull. Acad. Sci. USSR, Phys. Ser. 26, 1422 (1962) [Izv. Akad. Nauk SSR, Ser. Fiz. 26, 1398 (1962)].

Accuracy:

Systematic error < $\pm 5\%$. Random error < $\pm 2\%$.



Graphical Data H-3.2.

Secondary Electron Emission by Impact of Ions
on a Polycrystalline Nickel Target:
 H^+ , H_2^+ , H_3^+ , He^+ , on Ni
(Projectiles Incident Normally on Target)

Tabular Data H-3.3.
Secondary Electron Emission by Impact of Helium
Ions on a Polycrystalline Nickel Target:

He^+ , He^{2+} on Mo
(Projectiles Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion	
	He^{2+}	He^+
1.0 E-02	7.13 E-01	3.00 E-01
5.0 E-02	7.11 E-01	2.88 E-01
1.0 E-01	7.17 E-01	2.78 E-01
2.0 E-01	7.25 E-01	2.64 E-01
4.0 E-01	7.56 E-01	2.49 E-01
6.0 E-01	7.77 E-01	2.50 E-01
8.0 E-01	7.18 E-01	2.60 E-01
1.0 E 00	7.85 E-01	2.76 E-01
2.0 E 00		3.66 E-01
4.0 E 00		5.22 E-01
6.0 E 00		6.82 E-01
8.0 E 00		8.30 E-01
1.0 E 01		9.66 E-01
2.0 E 01		1.54 E 00
4.0 E 01		2.22 E 00

References:

He^{2+} on Mo: H.D. Hagstrum, Phys. Rev. 89, 244 (1953).

He^+ on Mo: H.D. Hagstrum, Phys. Rev. 104, 672 (1953). P. Mahadevan, J.K. Layton, D.B. Medved, Phys. Rev. 129, 79 (1963). D.W. Vance, Phys. Rev. 169, 252 (1967). V.A. Arifov, R.R. Rakhinov, O.V. Khozinskii, Bull. Acad. Sci. USSR 26, 1422 (1962) [Zh. Akad. Nauk. SSSR, Ser. Fiz. 26, 1398 (1962)]. V.G. Tel'kovskii, Soviet Phys., Doklady 1, 334 (1956).

Accuracy:

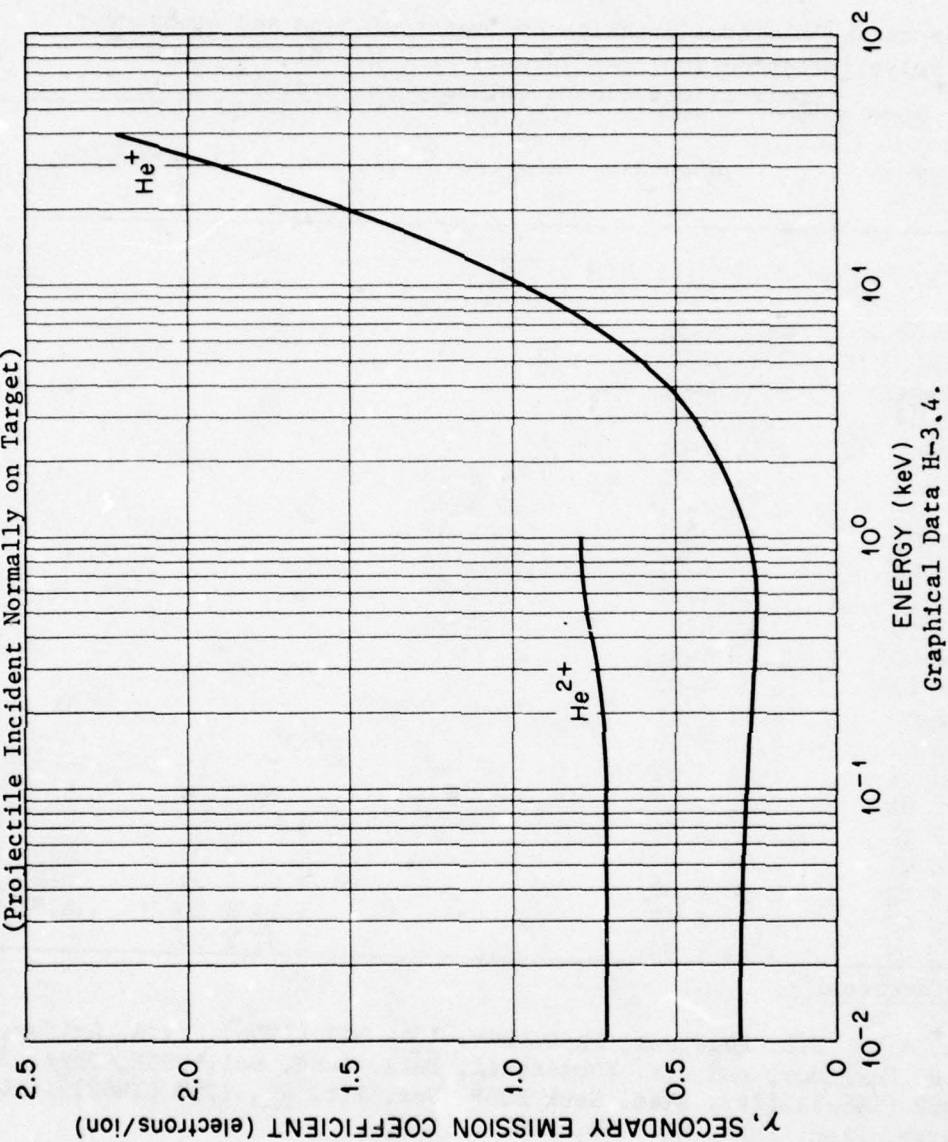
Systematic error $< \pm 2\%$. Random error $< \pm 2\%$.

Notes:

For further information on the dependence of γ with incidence angle, see D.W. Vance, Phys. Rev. 169, 252 (1967).

For information on the secondary electron emission coefficient as a function of incidence angle, see I.W. Evdokimov et al., Physica Status, Solidi 19, 407 (1967).

Secondary Electron Emission by Impact of Helium Ions on a
Polycrystalline Molybdenum Target: He^+ , He^{2+} on Mo
(Projectile Incident Normally on Target)



Graphical Data H-3,4.

Tabular Data H-3.5.

Secondary Electron Emission by Impact of Ions and Atoms on a
Polycrystalline Tungsten Target: He^+ , He , O^+ , O_2^+ on W
(Projectile Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion			
	He^+	He^0	O^+	O_2^+
1.0 E-02	2.92 E-01			
5.0 E-02	2.73 E-01			
1.0 E-01	2.63 E-01			
1.5 E-01	2.57 E-01			
2.0 E-01	2.50 E-01			
3.0 E-01	2.41 E-01	4.00 E-03		
4.0 E-01	2.39 E-01	2.00 E-02		
6.0 E-01	2.39 E-01	5.00 E-02		
8.0 E-01	2.44 E-01	7.40 E-02		
1.0 E 00	2.52 E-01	1.00 E-01		
2.0 E 00	3.40 E-01	2.26 E-01		
4.0 E 00	5.18 E-01			
6.0 E 00	6.80 E-01			
8.0 E 00	8.17 E-01			
1.0 E 01	9.32 E-01			
2.0 E 01	1.42 E 00			
4.0 E 01	2.36 E 00		2.76 E 00	3.38 E 00
6.0 E 01	2.44 E 00		3.42 E 00	4.47 E 00
8.0 E 01	2.74 E 00		4.05 E 00	5.42 E 00
1.0 E 02	2.98 E 00		4.60 E 00	6.21 E 00
1.2 E 02	3.11 E 00		5.14 E 00	6.81 E 00
1.4 E 02	3.16 E 00		5.57 E 00	

References:

He^+ + W: H.D. Hagstrum, Phys. Rev. 104, 317 (1956). V.A. Arifov, R.R. Rakhimov, and O.V. Khozinskii, Bull. Acad. Sci. USSR, Phys. Ser. 26, 1422 (1962). [Izv. Akad. Nauk SSSR, Ser. Fiz. 26, 1398 (1962)]. L.N. Large, Proc. Phys. Soc. 81, 1101 (1963).

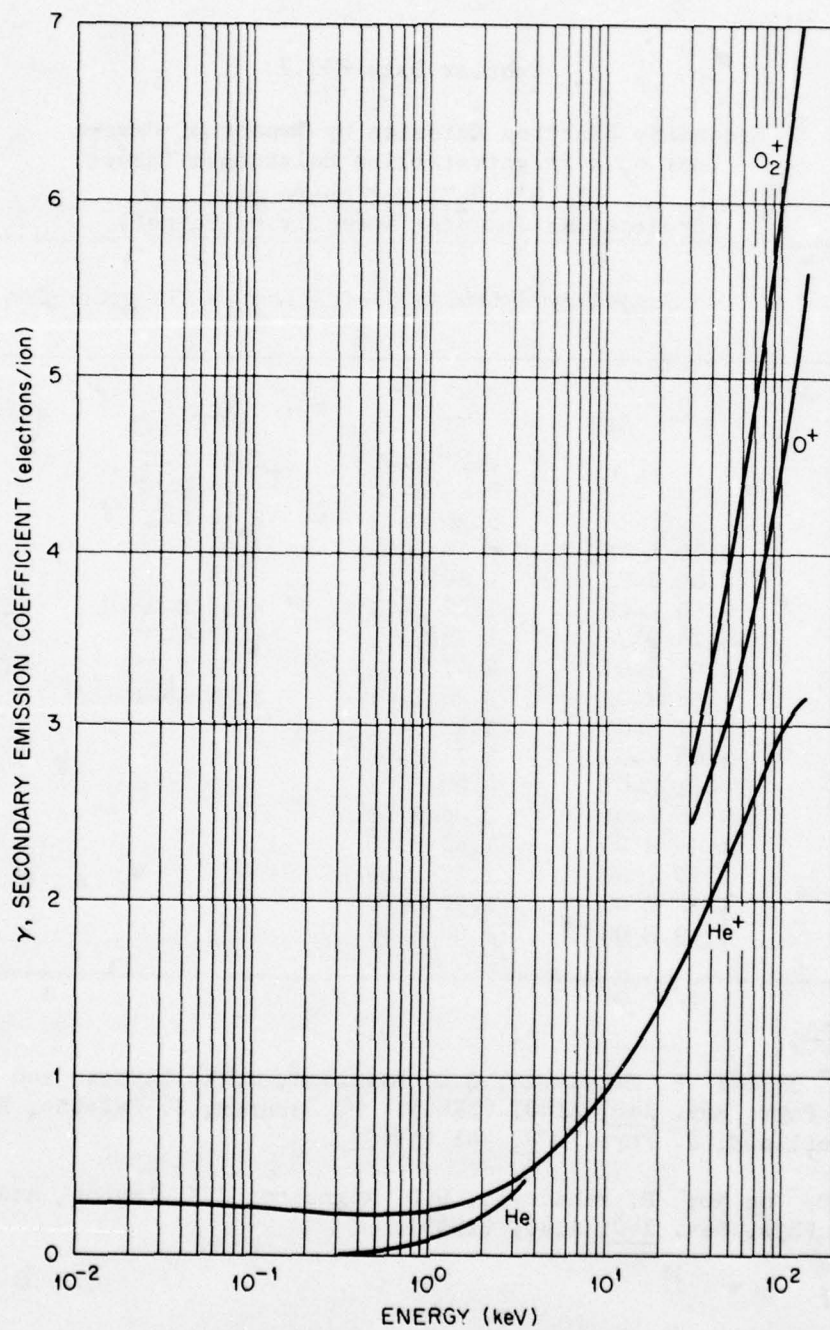
He^0 + W: H.W. Berry, J. Appl. Phys. 29, 1219 (1958).

O^+ and O_2^+ + W: L.N. Large, Proc. Phys. Soc. 81, 1101 (1963).

Accuracy:

Systematic error < $\pm 5\%$. Random error < $\pm 2\%$.

For information on the dependence of secondary emission flux with angle, see H.J. Klein, Zeits. für Physik, 188, 78 (1965).



Graphical Data H-3.6.
 Secondary Electron Emission by Impact of Ions and Atoms on a
 Polycrystalline Tungsten Target: He⁺, He, O⁺, O₂⁺ on W
 (Projectile Incident Normally on Target)

Tabular Data H-3.7.

Secondary Electron Emission by Impact of Oxygen
Ions on a Polycrystalline Molybdenum Target:

O^- , O^+ , O_2^- , O_2^+ on Mo
(Projectiles Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion			
	O^-	O^+	O_2^+	O_2^-
5.0 E-02		4.10 E-02	2.74 E-02	
1.0 E-01		4.20 E-02	2.75 E-02	
2.0 E-01		5.30 E-02	2.80 E-02	
4.0 E-01	9.00 E-03	8.10 E-02	3.06 E-02	1.40 E-03
6.0 E-01	2.00 E-02	1.20 E-01	3.40 E-02	1.08 E-02
8.0 E-01	3.50 E-02	1.42 E-01	4.38 E-02	2.03 E-02
1.0 E 00	5.74 E-02	1.78 E-01	6.00 E-02	3.25 E-02
1.4 E 00	1.05 E-01	2.41 E-01	1.05 E-01	6.10 E-02
1.8 E 00	1.58 E-01	3.20 E-01	1.58 E-01	8.80 E-02
2.0 E 00	1.82 E-01	3.32 E-01		
4.0 E 00	4.08 E-02	5.71 E-01		
8.0 E 00	7.61 E-01	9.20 E-01		
1.0 E 01	9.06 E-01	1.08 E 00		
1.5 E 01	1.24 E 00	1.40 E 00		
2.0 E 01	1.50 E 00	1.67 E 00		
2.5 E 01	1.72 E 00	1.90 E 00		
3.0 E 01	1.89 E 00	2.08 E 00		

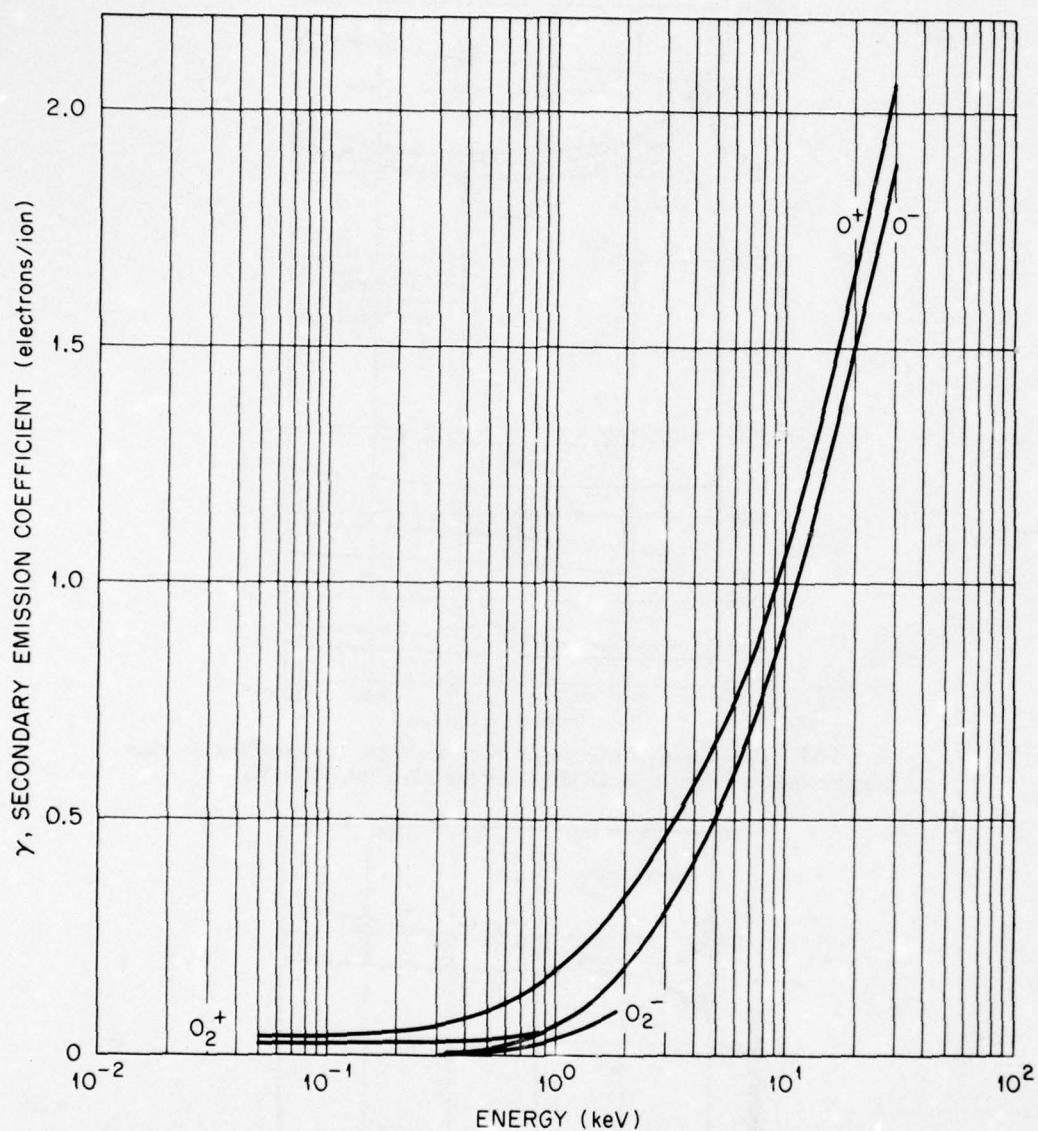
References:

O^+ and O^- on Mo: P. Mahadevan, G.D. Magnuson, J. K. Layton and C.E. Carlson, Phys. Rev. 140, A1407 (1965). M. Perdrix, S. Paletto, R. Goutte, and C. Guillaud, J. Phys. D 2, 441 (1969).

O_2^+ and O_2^- on Mo: P. Mahadevan, G.D. Magnuson, J.K. Layton, and C.E. Carlson, Phys. Rev. 140, A1407 (1965).

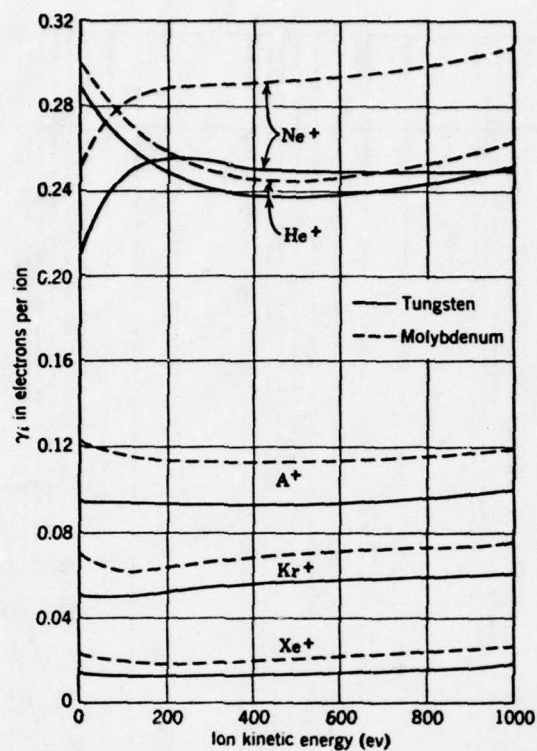
Accuracy:

Systematic error < \pm 5%. Random error < \pm 2%.

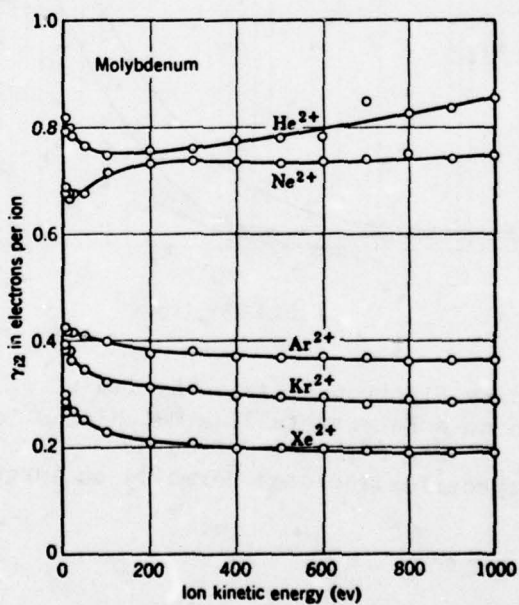


Secondary Electron Emission by Impact of Oxygen
Ions on a Polycrystalline Molybdenum Target:
 O^- , O^+ , O_2^- , O_2^+ on Mo
(Projectiles Incident Normally on Target)

Graphical Data H-3.8.

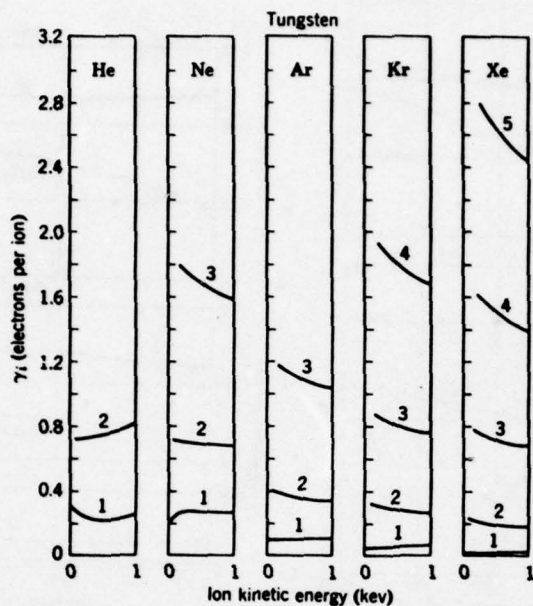


(a) Comparison of electron yields of noble gas ions on atomically clean tungsten and molybdenum. H. D. Hagstrum, *Phys. Rev.* 104, 672 (1956).

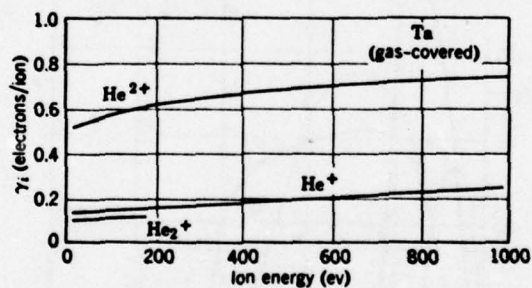


(b) Electron yields for doubly charged ions of the noble gases incident on atomically clean molybdenum. H. D. Hagstrum, *Phys. Rev.* 104, 672 (1956).

Graphical Data H-3.9.

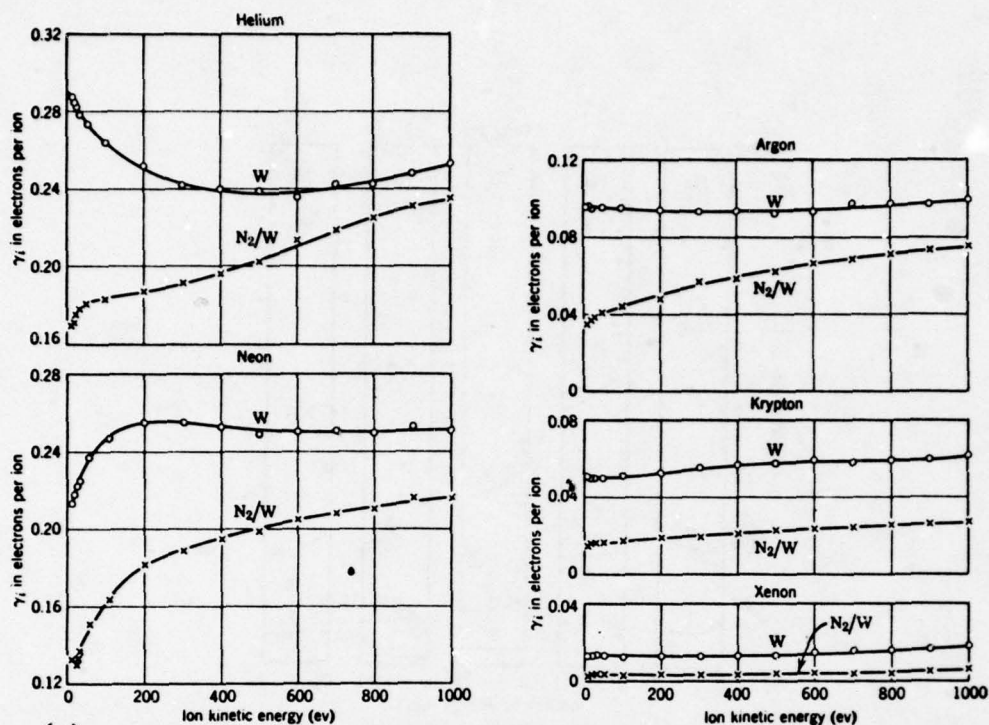


(a) Electron yields versus ion energy for singly and multiply charged positive ions of the noble gases incident on atomically clean tungsten. The charge of the ion is indicated at each curve. H. D. Hagstrum, *Phys. Rev.* 96, 325 (1954).

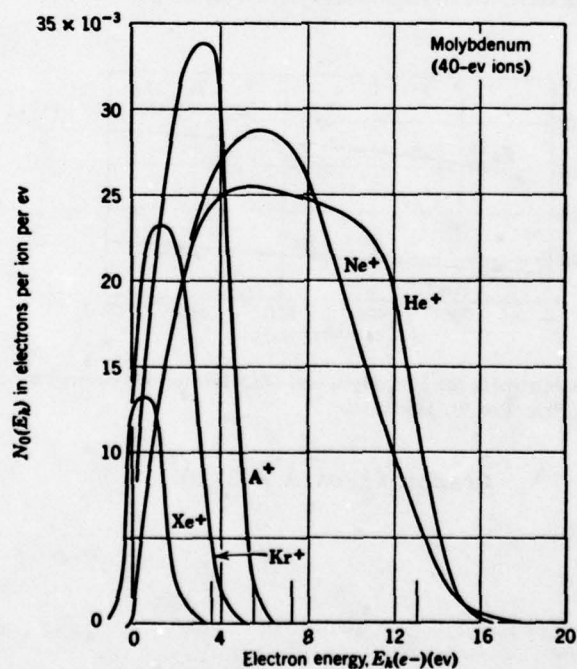


(b) Electron yields for He⁺, He²⁺, and He₃⁺ ions on gas-covered tantalum. H. D. Hagstrum, *Phys. Rev.* 91, 543 (1953).

Graphical Data H-3.10.

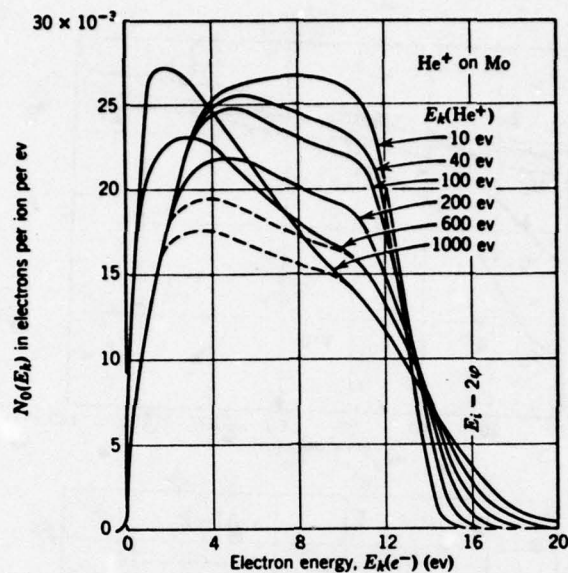


(a) . The variation of the electron yield with ion energy for singly charged noble gas ions on clean tungsten (W) and tungsten covered with a monolayer of N_2 (N_2/W). H. D. Hagstrum, *Phys. Rev.* 104, 1516 (1956).

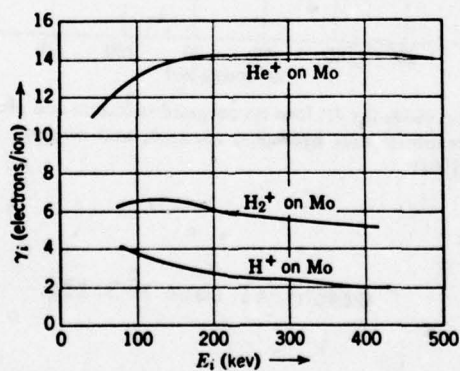


(b) . Energy distributions of secondary electrons ejected from Mo by 40-eV ions of the noble gases. H. D. Hagstrum, *Phys. Rev.* 104, 672 (1956).

Graphical Data H-3.11.

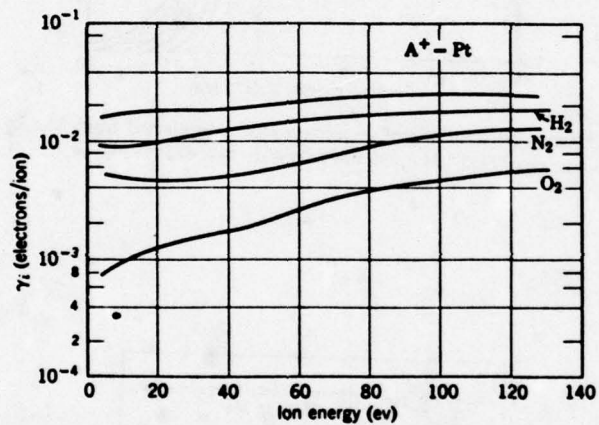
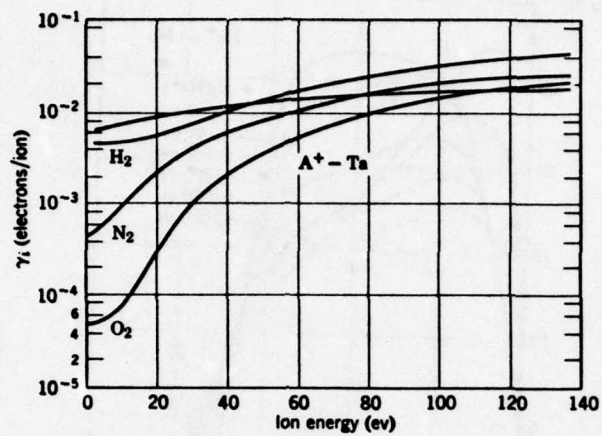


(a) Energy distributions of secondary electrons ejected from Mo by He^+ ions of various energies. H. D. Hagstrum, *Phys. Rev.* 104, 672 (1956).



(b) Electron yields for high-energy ions on molybdenum. A. G. Hill, W. W. Buechner, J. S. Clark, and J. B. Fisk, *Phys. Rev.* 55, 463 (1939).

Graphical Data H-3.12.



Electron yields for A^+ ions on outgassed tantalum and platinum and on these metals after treatment with hydrogen, nitrogen, and oxygen. J. H. Parker, *Phys. Rev.* 93, 1148 (1954).

Graphical Data H-3.13.

H-4. ELECTRON REFLECTION FROM SURFACES

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by low- and intermediate-energy electrons.	878

Tabular Data H-4.1.

Backscattering of Electrons Resulting from
Electron Impact on a Steel Surface
(Electrons Incident Normally to Surface)
e on Steel

Energy of Impact (keV)	Backscattering Coefficient η Electrons/Electron
4.0 E 01	9.20 E-02
8.0 E 01	1.58 E-01
1.0 E 02	1.66 E-01
1.5 E 02	1.85 E-01
2.0 E 02	1.92 E-01
3.0 E 02	1.96 E-01

Reference:

J.G. Trump and R.J. Van de Graaff, Phys. Rev. 75, 44 (1949).

Accuracy:

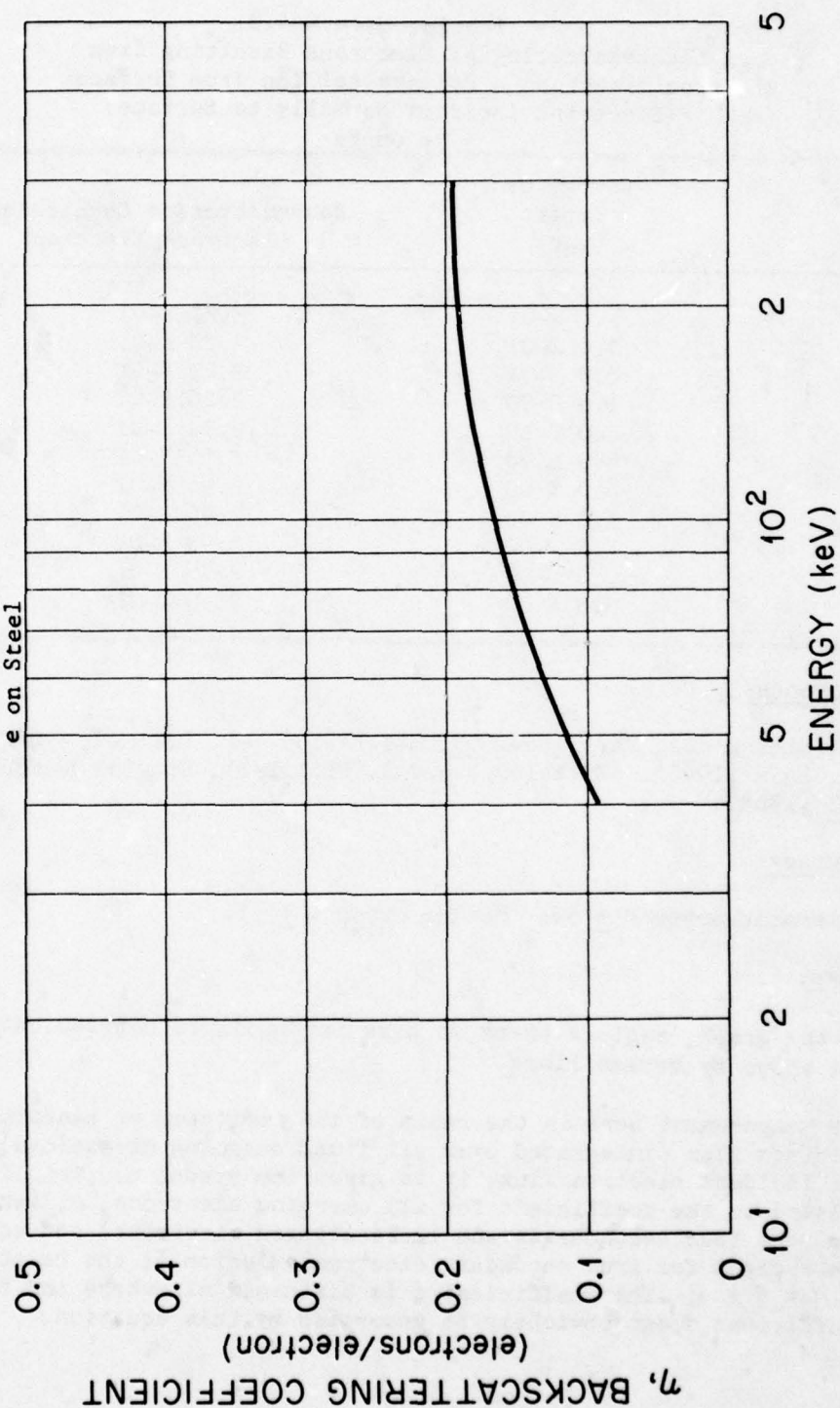
Unknown

Notes:

The measurement here is the ratio of the reflected or backscattered electron flux (integrated over all final outgoing directions) to the incident electron flux; it is given the symbol η . This is related to the coefficient for all emerging electrons, σ , (which includes true secondaries and backscattered electrons) and to the coefficient for true secondary electron emission δ ; the relationship is $\sigma = \delta + \eta$. The coefficient δ is discussed elsewhere and the coefficient σ can obviously be generated by this equation.

The type of steel used here is unspecified. There seems some possibility that the data are inaccurate towards lower energies.

Backscattering of Electrons Resulting from Electron Impact on a Steel Surface
(Electrons Incident Normally to Surface)
e on Steel



Graphical Data H-4.2.

Tabular Data H-4.3.
Backscattering of Electrons Resulting from
Electron Impact on a Polycrystalline Iron Surface
(Electrons Incident Normally to Surface)
e on Fe

Energy of Impact (keV)	Backscattering Coefficient η Electrons/Electron
3.0 E-01	2.22 E-01
4.0 E-01	2.20 E-01
8.0 E-01	2.20 E-01
1.0 E 00	2.20 E-01
2.0 E 00	2.30 E-01
4.0 E 00	2.76 E-01
8.0 E 00	2.98 E-01
1.0 E 00	2.99 E-01
1.5 E 00	2.93 E-01
2.0 E 00	2.76 E-01
3.0 E 00	2.49 E-01

References:

E.J. Sternglass, Phys. Rev. 95, 345 (1954). P. Palluel, Comptes Rendus 245, 1492 (1947). E. Weinryb and J. Philibert, Comptes Rendus 258, 4535 (1964).

Accuracy:

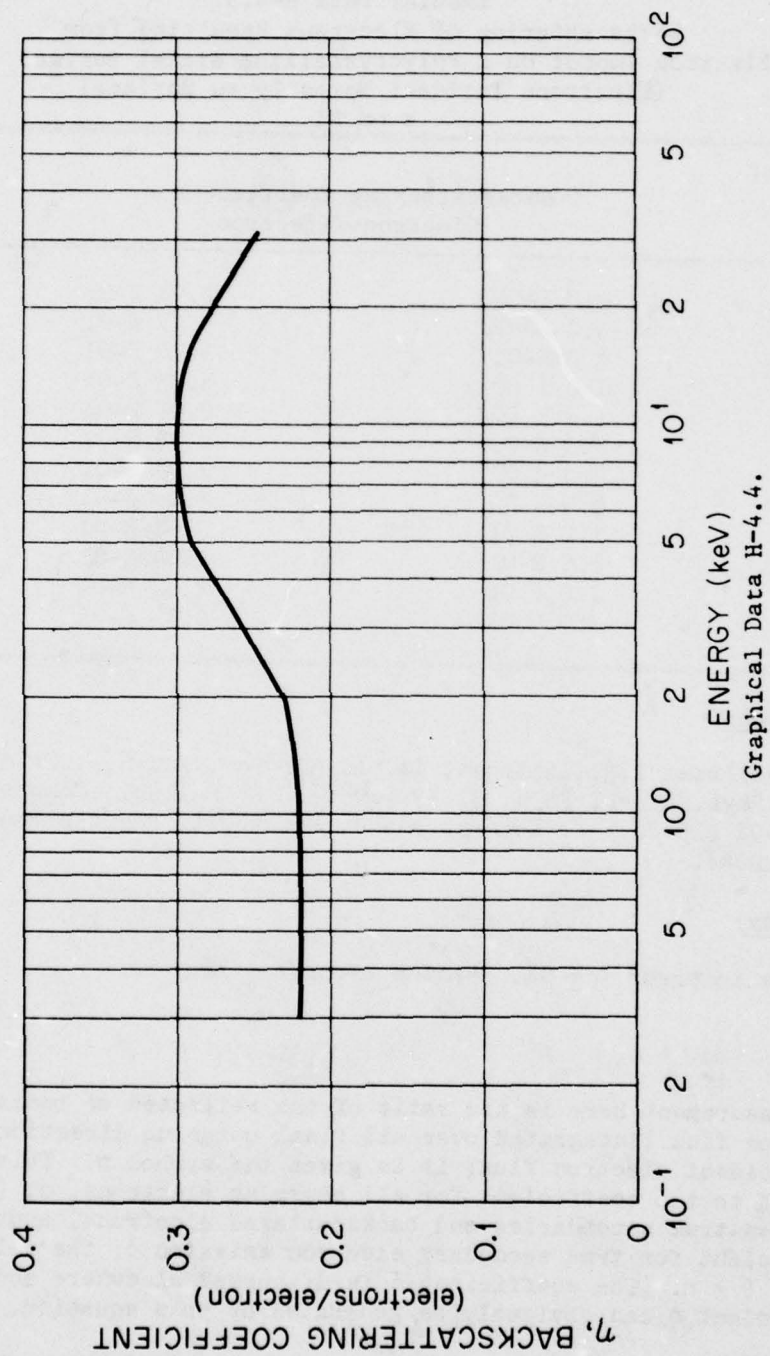
Systematic error < ± 5%. Random error < ± 5%.

Notes:

On the graph, regions where we have interpolated between data sets are shown by broken lines.

The measurement here is the ratio of the reflected or backscattered electron flux (integrated over all final outgoing directions) to the incident electron flux; it is given the symbol η . This is related to the coefficient for all emerging electrons, σ , (which includes true secondaries and backscattered electrons) and to the coefficient for true secondary electron emission δ ; the relationship is $\sigma = \delta + \eta$. The coefficient δ is discussed elsewhere and the coefficient σ can obviously be generated by this equation.

Backscattering of Electrons Resulting from Electron Impact on a Polycrystalline Iron Surface
 (Electrons Incident Normally to Surface)
 e on Fe



Tabular Data H-4.5.
Backscattering of Electrons Resulting from
Electron Impact on a Polycrystalline Nickel Surface
(Electrons Incident Normally to Surface)
e on Ni

Energy of Impact (keV)	Backscattering Coefficient η Electrons/Electron	
	2.0 E-01	2.50 E-01
	4.0 E-01	3.35 E-01
	8.0 E-01	3.50 E-01
	1.0 E 00	3.23 E-01
	1.5 E 00	2.97 E-01
	2.0 E 00	2.95 E-01
	4.0 E 00	2.99 E-01
	8.0 E 00	3.06 E-01
	1.0 E 01	3.07 E-01
	1.5 E 01	3.04 E-01
	2.0 E 01	2.97 E-01
	3.0 E 01	2.74 E-01

References:

A.R. Shul'man, I.R. Zakiyova, Iu. A. Morozov, and S.A. Fridrikhov, Soviet Phys., Tech. Phys. 3, 79 (1958). P. Palluel, Comptes Rendus 245, 1492 (1947). E. Weinryb and J. Philibert, Comptes Rendus 258, 4535 (1964).

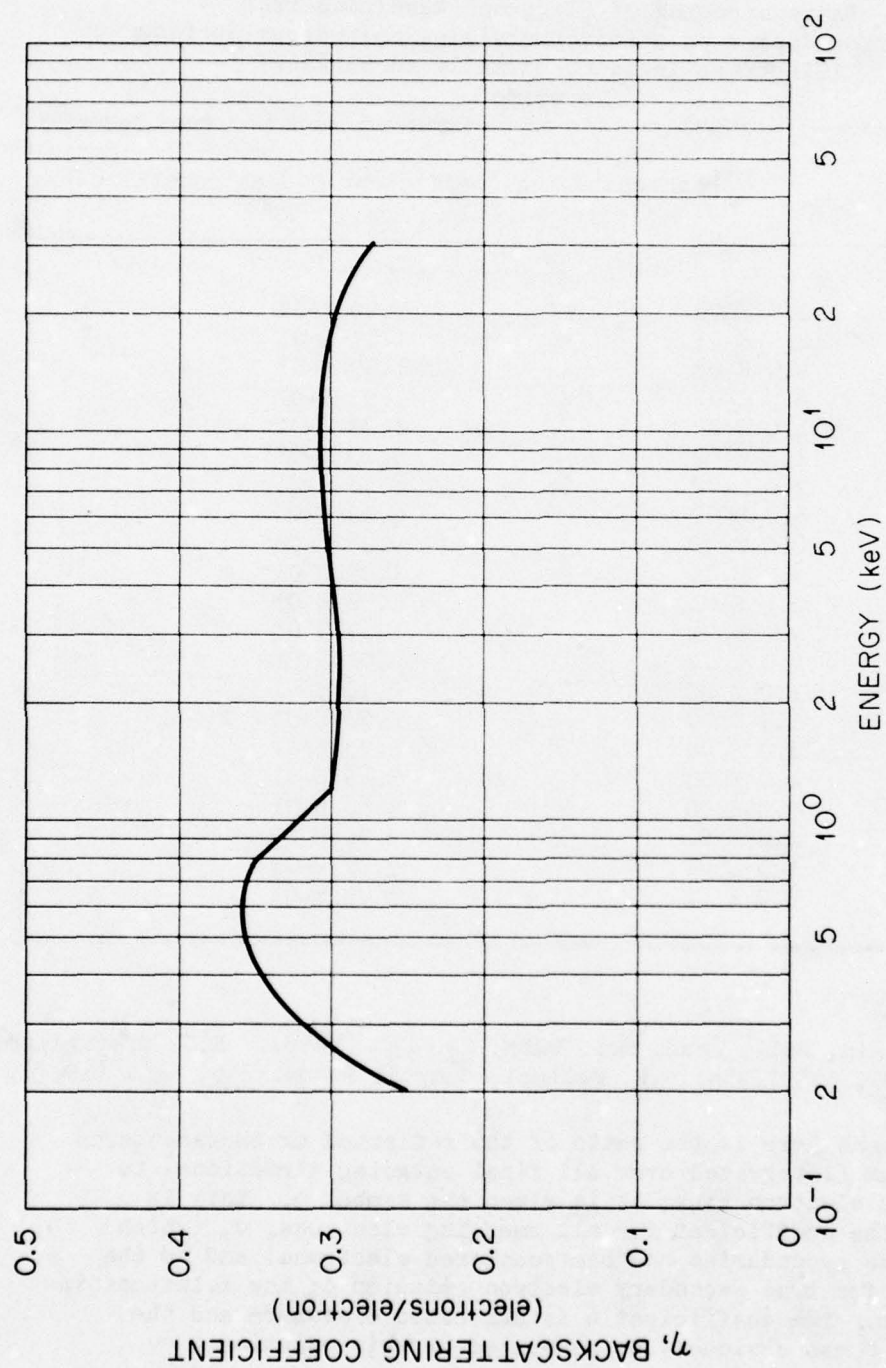
Accuracy:

Systematic error < $\pm 5\%$. Random error < $\pm 5\%$.

Notes:

The measurement here is the ratio of the reflected or backscattered electron flux (integrated over all final outgoing directions) to the incident electron flux; it is given the symbol η . This is related to the coefficient for all emerging electrons, σ , (which includes true secondaries and backscattered electrons) and to the coefficient for true secondary electron emission δ ; the relationship is $\sigma = \delta + \eta$. The coefficient δ is discussed elsewhere and the coefficient σ can obviously be generated by this equation.

On the graph, regions where we have interpolated between data sets are shown by broken lines.



Graphical Data H-4.6.
Backscattering of Electrons Resulting from Electron Impact on a Polycrystalline Nickel Surface
(Electrons Incident Normally to Surface)
e on Ni

Tabular Data H-4.7.
Backscattering of Electrons Resulting from
Electron Impact on a Polycrystalline Molybdenum Surface
(Electrons Incident Normally to Surface)
e on Mo

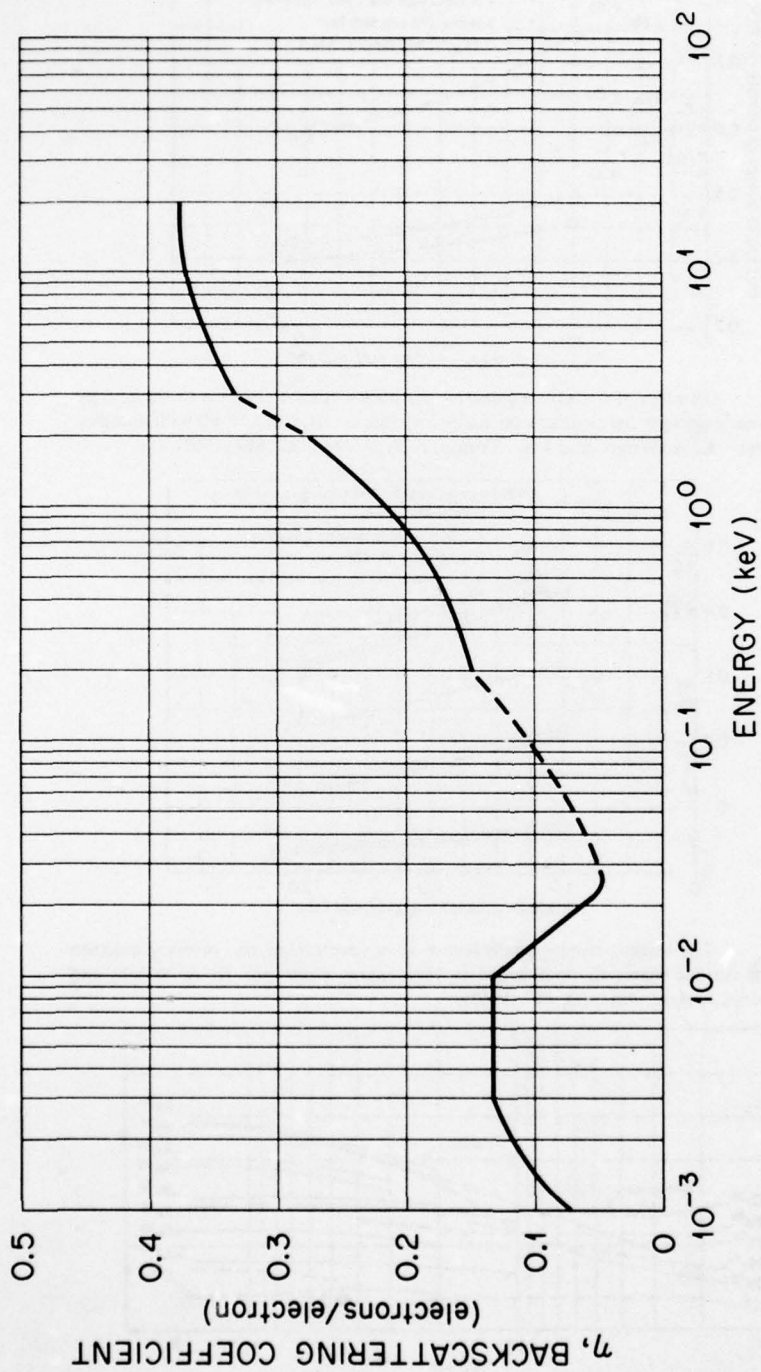
Energy of Impact (keV)	Backscattering Coefficient η Electrons/Electron	
1.0 E-03	7.00 E-02	
2.0 E-03	1.17 E-01	
4.0 E-03	1.33 E-01	
8.0 E-03	1.33 E-01	
1.0 E-02	1.33 E-01	
1.5 E-02	9.20 E-02	
2.0 E-02	6.50 E-02	
4.0 E-02	6.00 E-02	
8.0 E-02	9.20 E-02	
1.0 E-01	1.05 E-01	
2.0 E-01	1.50 E-01	
4.0 E-01	1.67 E-01	
8.0 E-01	2.00 E-01	
1.0 E 00	2.16 E-01	
1.5 E 00	2.50 E-01	
2.0 E 00	2.75 E-01	
4.0 E 00	3.45 E-01	
8.0 E 00	3.66 E-01	
1.0 E 01	3.70 E-01	
1.5 E 01	3.75 E-01	
2.0 E 01	3.75 E-01	

References:

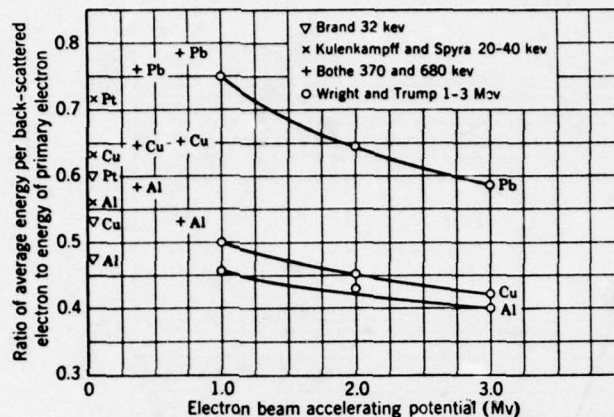
I.M. Bronshtein, Bull. Acad. Sci. USSR. 22, 442 (1958). E.J. Sternglass, Phys. Rev. 95, 345 (1954). P. Palluel, Comptes Rendus 245, 1492 (1947).

The measurement here is the ratio of the reflected or backscattered electron flux (integrated over all final outgoing directions) to the incident electron flux; it is given the symbol η . This is related to the coefficient for all emerging electrons, σ , (which includes true secondaries and backscattered electrons) and to the coefficient for true secondary electron emission δ ; the relationship is $\sigma = \delta + \eta$. The coefficient δ is discussed elsewhere and the coefficient σ can obviously be generated by this equation.

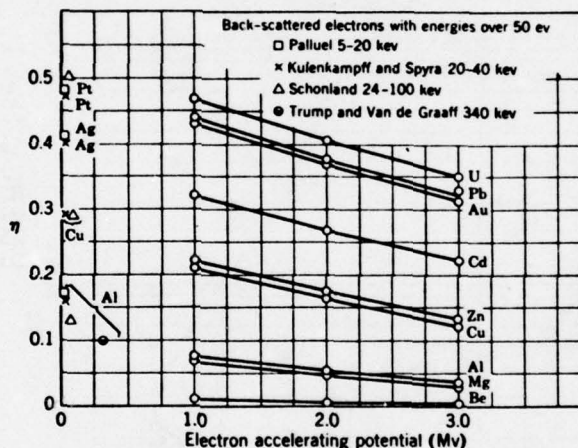
On the graph, regions where we have interpolated between data sets are shown by broken lines.



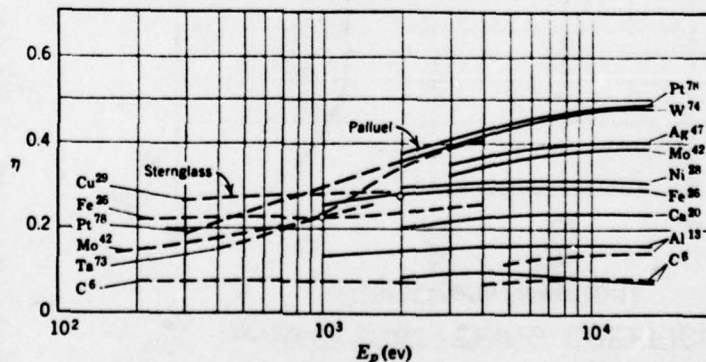
Graphical Data H-4.8.
 Backscattering of Electrons Resulting from Electron Impact on a Polycrystalline Molybdenum Surface
 (Electrons Incident Normally to Surface)
 e on Mo



The ratio of the average energy per backscattered electron to the energy of the primary electron for electrons normally incident on Al, Cu, and Pb with energies up to 3 Mev. K. A. Wright and J. G. Trump, *J. Appl. Phys.* 33, 687 (1962).



The backscattering coefficient η as a function of the primary electron energy for various materials bombarded by high-energy electrons. K. A. Wright and J. G. Trump, *J. Appl. Phys.* 33, 687 (1962).



The backscattering coefficient η as a function of primary electron energy for various materials bombarded by low- and intermediate-energy electrons.

Graphical Data H-4.9.

H-5. ION REFLECTION FROM SURFACES

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Scattering of H^0 , H^+ , H_2^+ , and H_3^+ from Solid Copper

Flux of scattered H^+ and H^0 integrated
over all scattered particle energies.

Primary Ion Energy: Various

Angle of Incidence α : 80°

Angle of Emergence β : 55°

(Data are for H^+ impact - for H^0 , H_2^+ , and H_3^+ see note below.)

Energy of Incident H^+ , (keV)	Particle Flux (Arbitrary Units)	
	Scattered H^+	Scattered $H^0 + H^+$
5.0 E 00		1.7 E-3
1.0 E 01	2.9 E-4	1.9 E-3
1.5 E 01	4.2 E-4	2.1 E-3
2.0 E 01	5.1 E-4	2.2 E-3
2.5 E 01	5.7 E-4	2.2 E-3
3.0 E 01	5.9 E-4	2.0 E-3
3.5 E 01	6.1 E-4	1.8 E-3
4.0 E 01	6.2 E-4	1.6 E-3
4.5 E 01		1.3 E-3

Reference:

H^+ + Au, Experimental: K. Morita, H. Akimune, T. Suita, Japanese J. Appl. Phys. 7, 916 (1968).

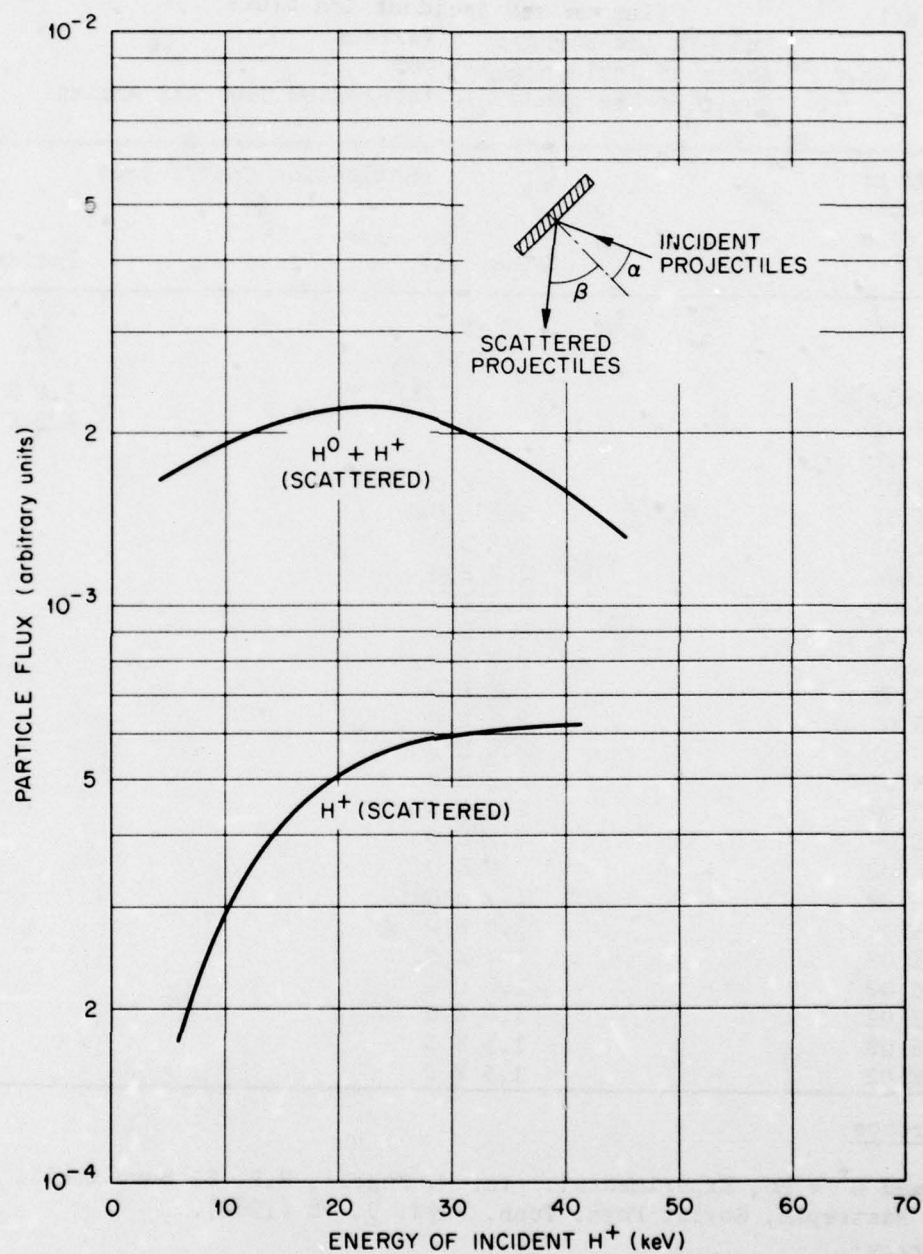
Accuracy:

Random error $< \pm 5\%$.

Note:

H^0 , H_2^+ , and H_3^+ impact. Yields of both H^+ and $H^0 + H^+$ are found to be the same as for H^+ impact at the corresponding velocity.

Scattering of H^0 , H^+ , H_2^+ , and H_3^+ from Solid Copper



Graphical Data H-5.2.

Tabular Data H-5.3.
 Scattering of He^+ and O^+ Ions from Solid Molybdenum
 Reflection Coefficient of the Scattered Ions
 (These data represent the ratio of the reflected ion
 flux to the incident ion flux)
 Primary Ion Energy: Various
 Angle of Incidence α : 90°
 Angle of Emergence β : Integrated Over All Angles

Energy of Incident Particles (keV)	Reflection Coefficient (%)	
	Incident	Incident
	<u>He^+</u>	<u>O^+</u>
5.0 E 00		3.2 E 0
1.0 E 01		4.3 E 0
1.5 E 01		
2.0 E 01	2.0 E 0	
2.5 E 01	2.2 E 0	
3.0 E 01	2.3 E 0	
3.5 E 01	2.4 E 0	
4.0 E 01	2.5 E 0	
4.5 E 01	2.6 E 0	
5.0 E 01	2.7 E 0	
6.0 E 01	2.7 E 0	
7.0 E 01	2.5 E 0	
8.0 E 01	2.4 E 0	
9.0 E 01	2.3 E 0	
1.0 E 02	2.2 E 0	
1.1 E 02	2.1 E 0	
1.2 E 02	2.0 E 0	
1.3 E 02	1.9 E 0	
1.4 E 02	1.8 E 0	
1.5 E 02	1.7 E 0	
1.6 E 02	1.6 E 0	
1.7 E 02	1.6 E 0	
1.8 E 02	1.5 E 0	
1.9 E 02	1.5 E 0	

Reference:

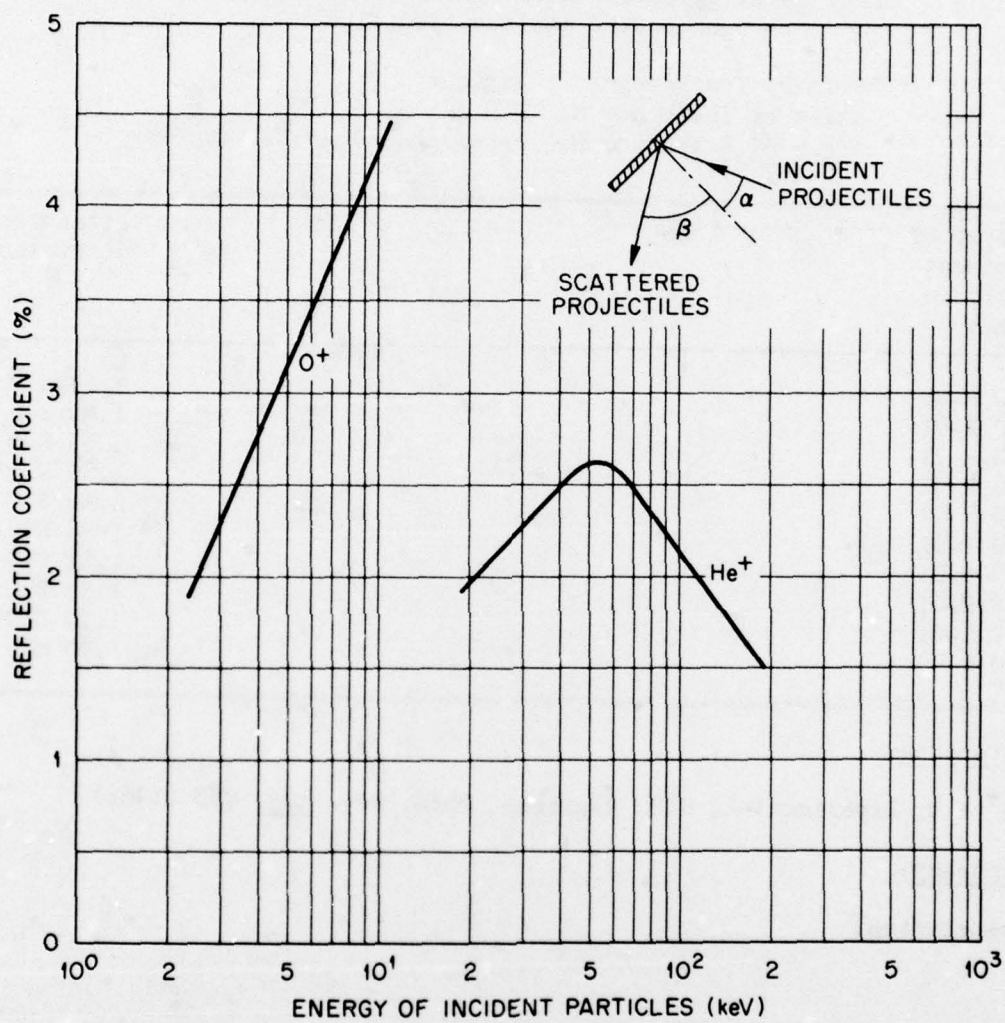
He^+ and O^+ + Mo, Experimental: Ya. M. Fogel', R.P. Slabospitskii, and A.B. Rastrepin, Soviet Phys. Tech. Phys. 5, 58 (1960).

Accuracy:

Unspecified. The validity of the technique used for this measurement has not been independently confirmed and the accuracy of the data is therefore suspect.

Scattering of He^+ and O^+ Ions from Solid Molybdenum-

Reflection Coefficient of the Scattered Ions.



Graphical Data H-5.4.

Tabular Data H-5.5.

Scattering of He^+ from Solid Tungsten-

Reflection Coefficient of the Scattered Ions.

These data represent the ratio of the reflected ion flux to the incident ion flux.

Primary Ion Energy: Various
Angle of Incidence α : 90°
Angle of Emergence β : Integrated Over All Angles

Energy of Incident Particle (keV)	Reflection Coefficient (%)
1.0 E-01	1.67 E 0
2.0 E-01	1.80 E 0
3.0 E-01	1.65 E 0
4.0 E-01	1.50 E 0
5.0 E-01	1.40 E 0
6.0 E-01	1.38 E 0
7.0 E-01	1.43 E 0
8.0 E-01	1.55 E 0
9.0 E-01	1.70 E 0
1.0 E 00	1.90 E 0

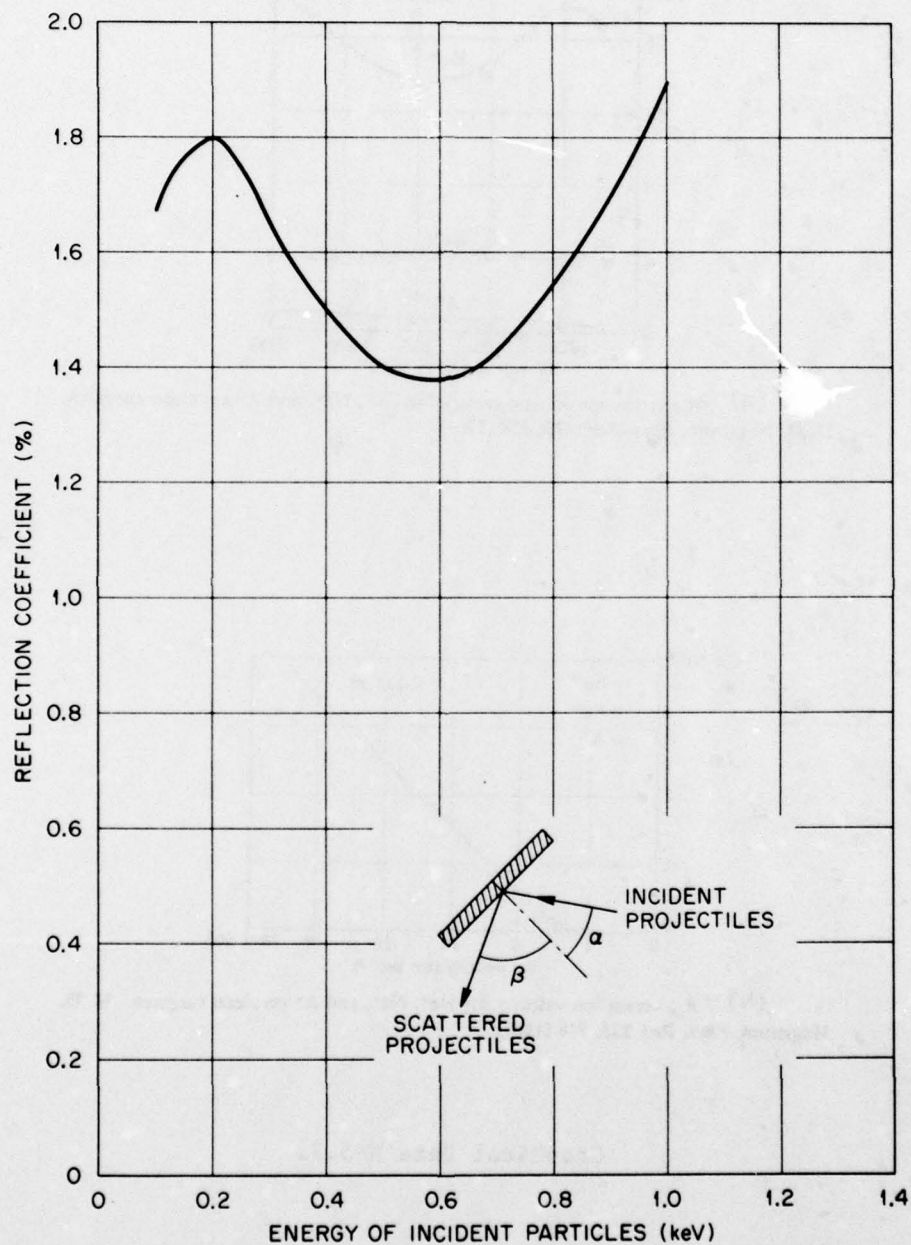
Reference:

He^+ + W, Experimental, H.D. Hagstrum, Phys. Rev. 123, 758 (1961).

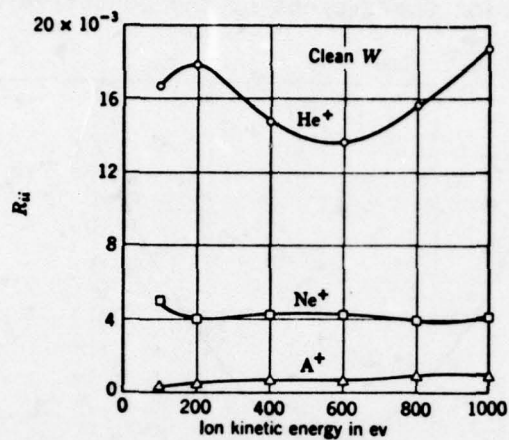
Accuracy:

Unspecified.

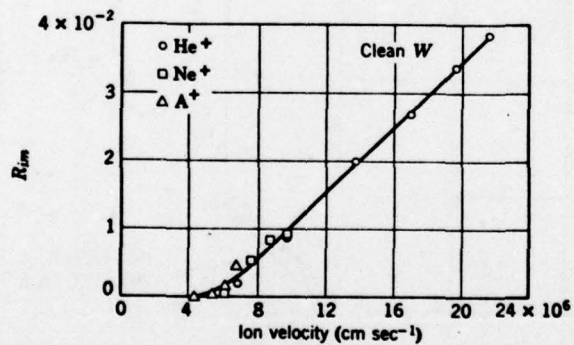
Scattering of He^+ from Solid Tungsten-
Reflection Coefficient of the Scattered Ions.



Graphical Data H-5.6.



(a) . R_{ii} versus ion kinetic energy for He⁺, Ne⁺, and A⁺ on clean tungsten. H. D. Hagstrum, *Phys. Rev.* 123, 758 (1961).



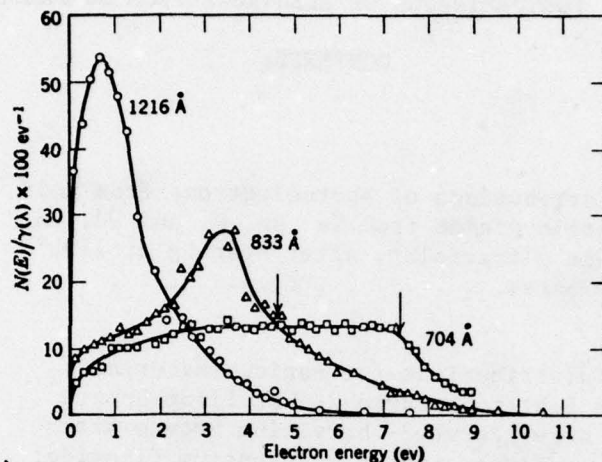
(b) . R_{im} versus ion velocity for He⁺, Ne⁺, and A⁺ on clean tungsten. H. D. Hagstrum, *Phys. Rev.* 123, 758 (1961).

Graphical Data H-5.7.

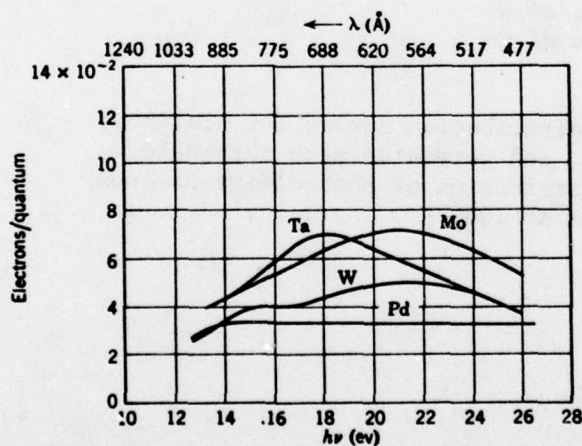
H-6. PHOTOEMISSION OF ELECTRONS FROM SURFACES

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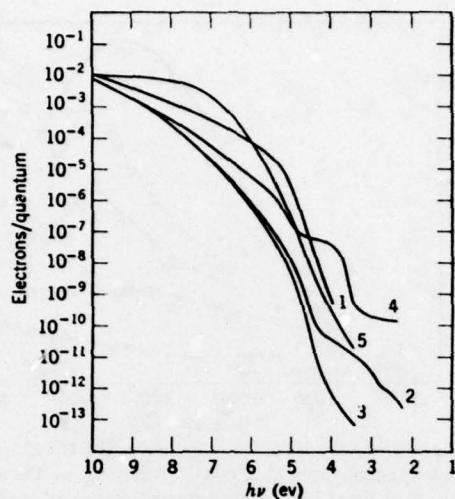


(a) Energy distributions of photoelectrons from gold. This sample had a work function of about 4 ev. W. C. Walker and G. L. Weissler, *Phys. Rev.* **97**, 1178 (1955).

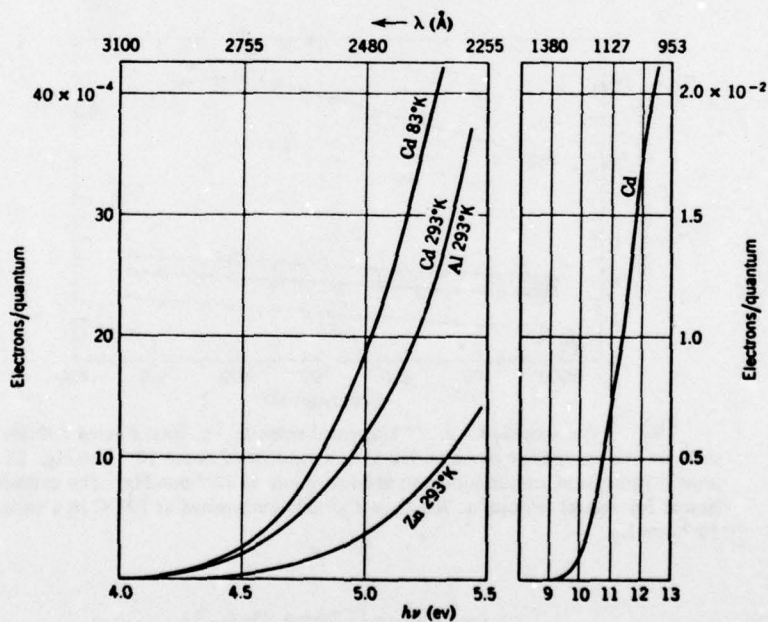


(b) Photoelectric yields from Ta, Mo, W, and Pd in the extreme ultraviolet, after heating at 1100°C for two minutes. N. Wainfan, W. C. Walker, and G. L. Weissler, *J. Appl. Phys.* **24**, 1318 (1953); W. C. Walker, N. Wainfan, and G. L. Weissler, *J. Appl. Phys.* **26**, 1366 (1955).

Graphical Data H-6.1.

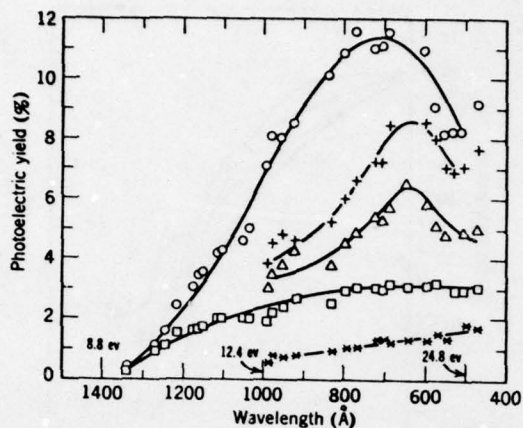


(a) Spectral distributions for various materials: Curve 1—platinum; curve 2—beryllium bronze oxidized once; curve 3—beryllium bronze after second oxidation; curve 4—strontium fluoride; curve 5—copper treated with iodine (CuI). A. M. Tyutikov and Yu. A. Shuba, *Optics and Spectroscopy* 9, 332 (1960).

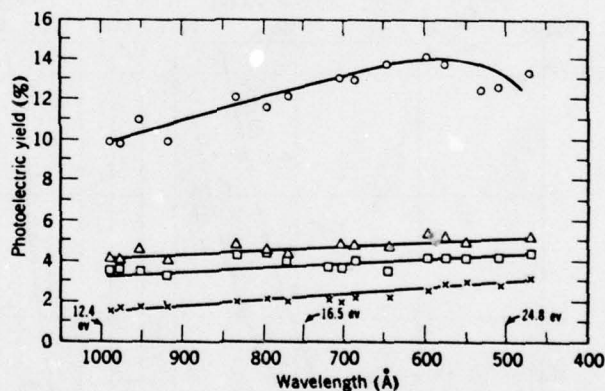


(b) Photoelectric yields from Al, Cd, and Zn. R. F. Baker, *J. Opt. Soc. Am.* 28, 55 (1938); R. Suhrmann and J. Pietrzyk, *Z. Phys.* 122, 600 (1944).

Graphical Data H-6.2.

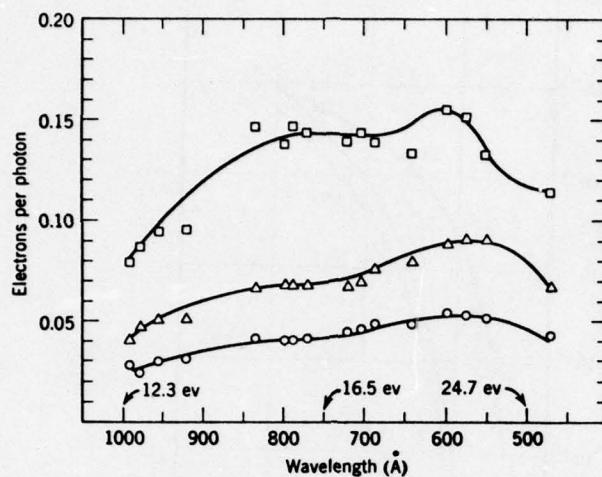


(a) Photoelectric yield of Ni. \circ Untreated cathode. \square Heat-treated cathode in equilibrium with residual gases at about 10^{-5} mm Hg. $*$ Cathode maintained at 900°C in a vacuum of 10^{-5} mm Hg. \triangle Heat-treated cathode at room temperature after exposure to O_2 at 0.1 mm Hg for one half hour. $+$ Heat-treated cathode, heated in 0.05 mm Hg of O_2 at 800°C for one minute.

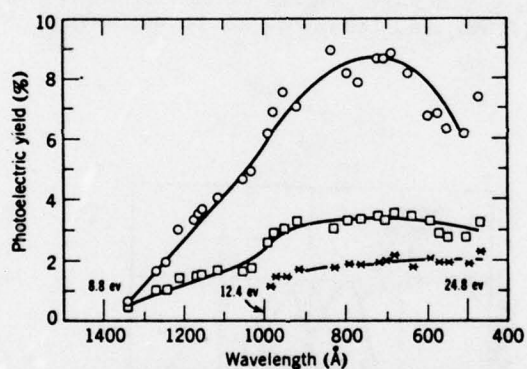


(b) Photoyield of Au. \circ Untreated cathode. \triangle Heat-treated cathode. The cathode was treated for 40 sec at 900°C in a vacuum of about 10^{-5} mm Hg. \square Heat-treated cathode in equilibrium with residual gases at 10^{-5} mm Hg. The cathode was heated for several minutes at 900°C . $*$ Cathode maintained at 800°C in a vacuum of 10^{-5} mm Hg.

Graphical Data H-6.3.

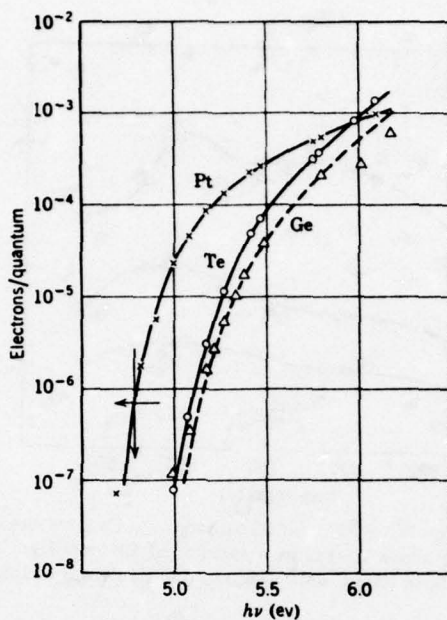


(a) Photoyield of W. \square Untreated cathode. \triangle Cathode heated for five minutes at a temperature above 1000°C in a vacuum of 10^{-8} mm Hg. \circ Cathode heated at a temperature above 1000°C until yield reproducibility was established.

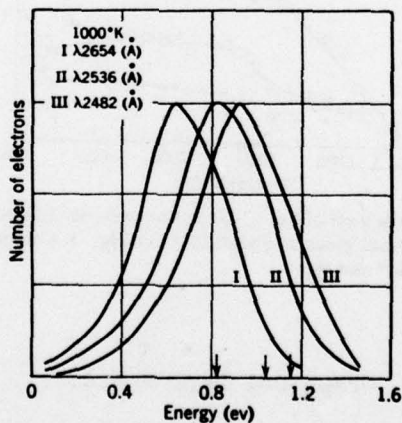


(b) Photoelectric yield of Cu. \circ Untreated cathode. \square Heat treated cathode in equilibrium with residual gases at about 10^{-8} mm Hg. $*$ Cathode maintained at 500°C in a vacuum of 10^{-8} mm Hg.

Graphical Data H-6.4.



(a) Spectral distribution curves for platinum, tellurium, and germanium near threshold. The solid curve through the platinum data was obtained from Fowler's theory. The three surfaces studied here had the same thermionic work function, 4.76 ev. L. Apker, E. Taft, and J. Dickey, *Phys. Rev.* **74**, 1462 (1948).



(b) Energy distributions of photoelectrons from molybdenum at 1000°K. The arrows indicate the maximum energies at 0°K. W. W. Roehr, *Phys. Rev.* **44**, 866 (1933).

Graphical Data H-6.5.

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